THE COMPLETE
TECHNICAL PAPER PROCEEDINGS
FROM:

NCTA Technical Papers

A FEEDFORWARD GAIN BLOCK

G. Luettgenau
J. Powell

TRW Semiconductors, Inc.

ABSTRACT

This paper describes the characteristics and in-system performance of a compact feed-forward gain block which is applied in much the same way as conventional hybrids.

The feed-forward approach toward increased linearity and output capability yields a high return on an investment in cost and power consumption.

Detailed analyses are performed with respect to trunking, distribution and general system upgrading. Operation with various degrees of tilt and output level is evaluated.

The feasibility of combining feed-forward blocks with normal hybrids is discussed. The data presented allow the system designer to make performance and cost comparisons with alternate approaches.

In conclusion, mechanical and thermal aspects are discussed. A prognosis for future developments in the area of integrated feed-forward amplifiers is given.

INTRODUCTION

The feed-forward type amplifier established itself as the deluxe model of CATV amplifiers. As such it found a niche for special applications.

Recently, however, feedforward has become an appealing solution for a wide range of applications. Bandwidth extensions, coupled with increased channel loading, have pushed the requirements for normal hybrid performance to the limits. In more and more cases the feed-forward approach offers a technical solution on a broad front.

In general, a trunk or line-extender amplifier can be realized from a combination standard hybrid and feed-forward circuit. Using volume price projections, the cost ratio between a conventional amplifier (two hybrids) and a feed-forward system (one hybrid plus a feed-forward block) is 1:3.5. The ratio of power consumption is 1:2.5. To put these numbers into perspective, one must realize that the feed-forward gain block has the same output capability as at least eight normal hybrids in parallel.

In the following the performance and construction details of an integrated feed-forward gain block are discussed.

A FEEDFORWARD GAIN BLOCK

Trunk Performance

The excellent distortion characteristics of the feed-forward amplifier may be used to extend the trunk length, to increase station spacing or to minimize distortion. Depending on the design objective, the feed-forward block is combined with a second block, or with a standard hybrid, to form a station amplifier. A computer analysis of the maximum trunk reach was performed, since this is a useful figure of merit.

Figure 1 shows the characteristics of the various gain blocks used in the analysis. FF1 is the currently available feed-forward block. FF2 is an anticipated second generation device. G22, G18 and G12 are standard hybrids.

	FF1	FF2	G22	G18	G12
Gain (450)	24	28	23	19.5	12.5
Gain-Slope	1	1	1	1	1
NF (450)	8	7	6	6	6.5
NF-Slope	1	1	1.5	1.5	1.2
CTB*	-75	-75	-58	-59	-57
CTB-Slope	7	7	9	9	7

* CTB = 60 CH @ H22 46dBmV flat
all numbers are dB values

Figure 1. Gain Block Characteristics

The analysis assumed the following station amplifier characteristics:

- o Flat input loss = 2dB
- o Flat interstage loss = 10dB
- o Pre-amp operated with flat output
- o Post-amp output tilted with equalization before and after pre-amp, as required.

The trunk specifications are CTB = -59dB, CNR = 43dB, minimum performance at any channel. The analysis was performed for output tilts in steps of 1dB. It was stopped, when a further increase in tilt did not yield a reach increase.

The results of the various computer runs are tabulated below. In order to preserve space, only the values of zero, maximum, and 6dB tilt (if applicable) are quoted. The reader is invited to study the performance and draw conclusions.

G18 + G18 (27dB Spacing)

Tilt (dB)	V_{out}(dBmV)	Cascade	Reach (dB)
0	32.5	20	540
6	33.4	24	648
9	33.9	27	729

FF1 + FF1 (36dB Spacing)

Tilt (dB)	V_{out}(dBmV)	Cascade	Reach (dB)
0	42.0	15	540
6	43.0	19	684
12	44.0	23	828

FF2 + FF2 (44dB Spacing)

Tilt (dB)	V_{out}(dBmV)	Cascade	Reach (dB)
0	45.5	6	264
6	46.5	8	352
13	47.7	11	484

G12 + FF1 (24.5dB Spacing)

Tilt (dB)	V_{out}(dBmV)	Cascade	Reach (dB)
0	34.6	66	1617
2	34.8	70	1715

G18 + FF1 (31.5dB Spacing)

Tilt (dB)	V_{out}(dBmV)	Cascade	Reach (dB)
0	36.9	41	1291
4	37.4	46	1449

G22 + FF1 (35dB Spacing)

Tilt (dB)	V_{out}(dBmV)	Cascade	Reach (dB)
0	39.7	21	735
6	40.4	25	875
9	40.8	27	945

G12 + FF2 (28.5dB Spacing)

Tilt (dB)	V_{out}(dBmV)	Cascade	Reach (dB)
0	36.3	51	1453
2	36.6	55	1567

Line Extenders

In line-extender and bridger applications, the feed-forward circuit allows operation at very high output levels. Because of this, more taps with high tap loss and low insertion loss can be used, thereby extending the amplifier spacing and substantially increasing the number of subscribers served per amplifier.

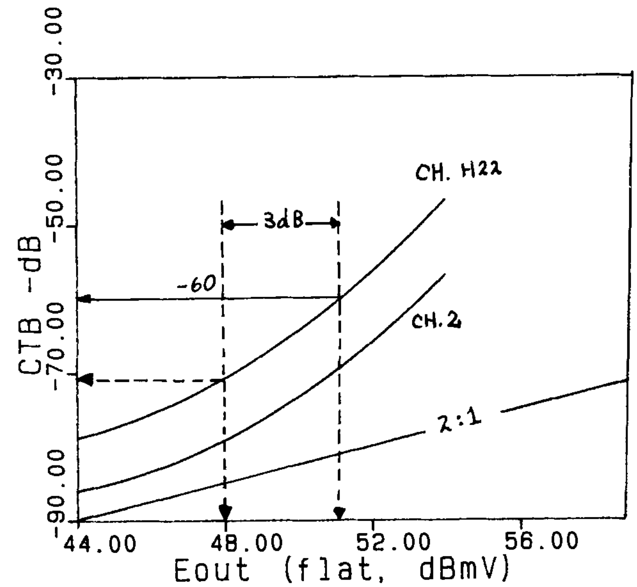


Figure 2. CTB Versus Flat Output

Figure 2 shows CTB as a function of output level for the amplifier type FF1. The curve would also pertain, approximately, to a combination of FF1 with any standard gain block type, since the pre-amp CTB contribution is less than 1dB.

A CTB requirement of -66dB for line-extenders is common. There should be a "headroom" of 3dB in output capability, corresponding to (theoretically) -60dB CTB. Because of deviations from the "two-for-one" law at high output levels, the maximum output voltage must therefore be limited to a value 3dB below the point at which CTB is -60dB. For a flat spectrum this level is 48dBmV. As shown in Figure 3, a 9dB tilt raises the maximum output to 51dB and improves the low level performance by 10dB. This welcome phenomenon can be understood readily by recognizing that tilted operation results in reduced total power to be handled by the amplifier, thus providing more headroom.

Since, further, a modulated TV signal has less power than the carrier (peak-sync) power used for CTB testing, it is to be expected that under real life conditions the overload point is moved to even higher output levels. To investigate this possibility, a test set-up was assembled which allowed the measurement of CTB caused by fully modulated signals. Refer to Figure 4. The analyzer was used as a receiver (Zero-Span, Linear Mode) with its video output fed to a wave-analyzer, which measured RMS signals in a wideband or 20Hz narrow band mode.

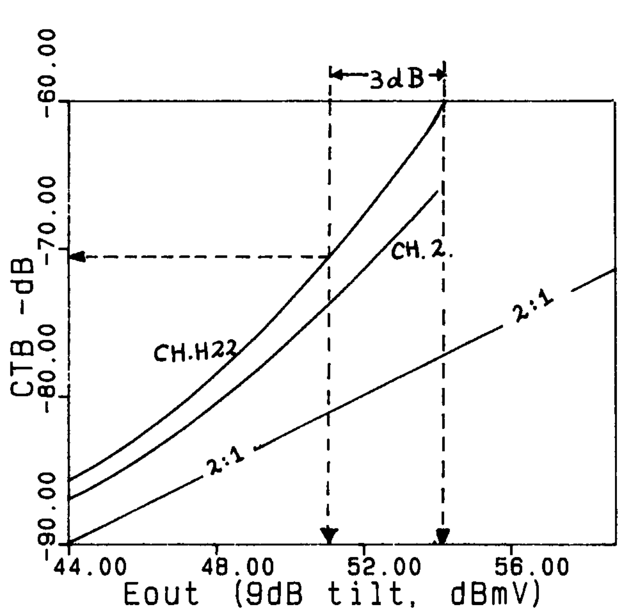


Figure 3. Operation with 9dB Tilt

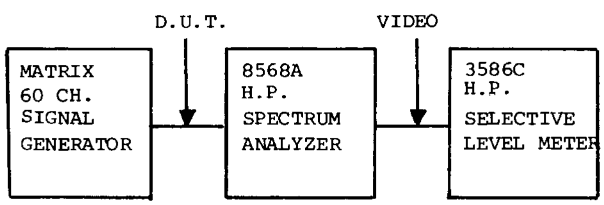


Figure 4. Special CTB Test Set-Up

Figure 5 shows the composition of the video signal analyzed. By subtracting noise and crossmodulation sidebands from the composite signal, the CTB component was derived. The results are shown in Figure 6. In hindsight the outcome is quite plausible. Since all 59 interfering carriers were synchronously modulated by a symmetrical squarewave, CTB components were generated only during half of the time. Thus the CTB power is halved, regardless of output level. Therefore, one may conclude that synchronous modulation reduces the value of CTB noise, but does not change the overload point. The situation of synchronous modulation has a low probability in real life. All synchronization pulses would have to occur at the same time. It is more likely that the amplitudes of all video signals involved are different from each other. Making the simplifying assumption that each signal has a random value between 0 and 1 (= unmodulated carrier), the RMS triple beat noise is 7.2dB below the value measured with all signals at full carrier amplitude. For this case both a CTB improvement and an increase in overload threshold is expected. The validity of this prediction could only be established by a viewer test. It appears to be not unreasonable to expect an improvement in headroom of at least 3dB.

Operating a line-extender at very high output levels requires consideration of certain interrelations:

The spacing between line-extenders is given by

$$\text{Spacing} = E_{out} - E_{min}$$

where

E_{out} = Output capability

and

E_{min} = Minimum level on the distribution cable, typically 16dBmV

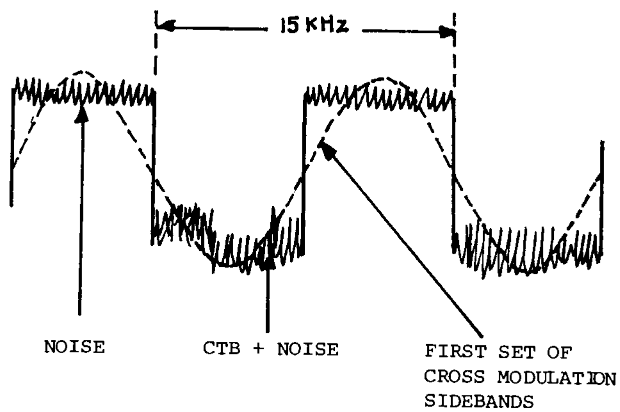


Figure 5. Video Signal

A line extender with an output capability of 51dBmV will therefore need a gain (spacing) of 35dB. The losses between amplifiers can be divided into flat loss (from taps) and cable loss. Using typical lot-size, tap-loss and cable-loss numbers, one may calculate that for a spacing of 35dB, 12 taps with a total flat loss of 12dB and 23dB of cable (450MHz) may be used.

For 50-450MHz operation, cable losses (dB) can be assumed to vary at a ratio of 1:3. Under this condition the following relations exist:

Cable-loss (450)= 3 * tilt -2 * drop-cable loss(450)
Tolerance = cable-loss /3

Tolerance is the range of voltages available to the subscriber. For instance, for a tolerance of 6dB, the average signal voltage would be +3dBmV. Channel 2 would be at 0dBmV at the beginning of the cable and at +6dBmV at the end. The opposite would hold for Channel H22. The best tolerance achieveable for 23dB of cable is 7.7dB. The minimum amount of output tilt for the line-extender depends on the length and quality of the drop-cable used. It would seem that for example given, 10dB or more is appropriate. The conclusion to be drawn is that the feed-forward line extender may have to be operated with more tilt than the usual values.

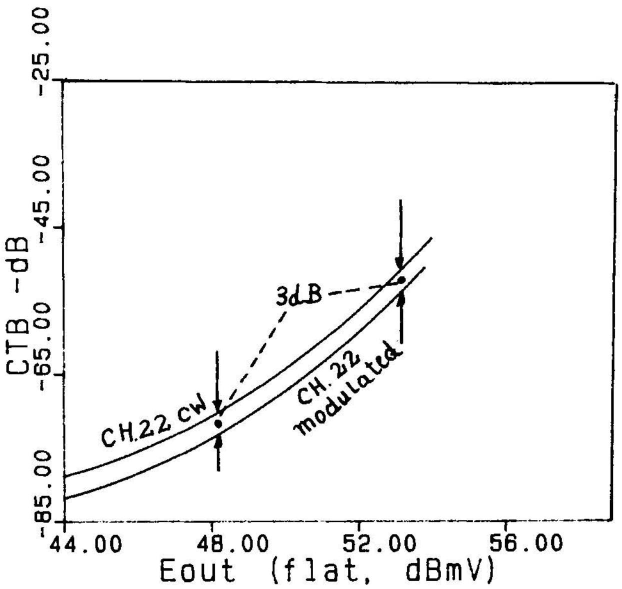


Figure 6. CTB in Modulated System

Package Outline

The feed-forward amplifier is a plug-in module, pre-tuned and fully characterized, that has been designed to replace standard amplifiers in CATV amplifying stations. Due to its small size a minimum of mechanical modifications are usually required.

The photograph (Figure 7) shows the package configuration chosen. It is the best compromise between size, performance and manufacturing costs.

The dimensions are 2 inches x 2.5 inches x 0.8 inches. There are 5 pins on each side (Figure 8) spaced 250 mils apart and 0.5 inch above the mounting surface.

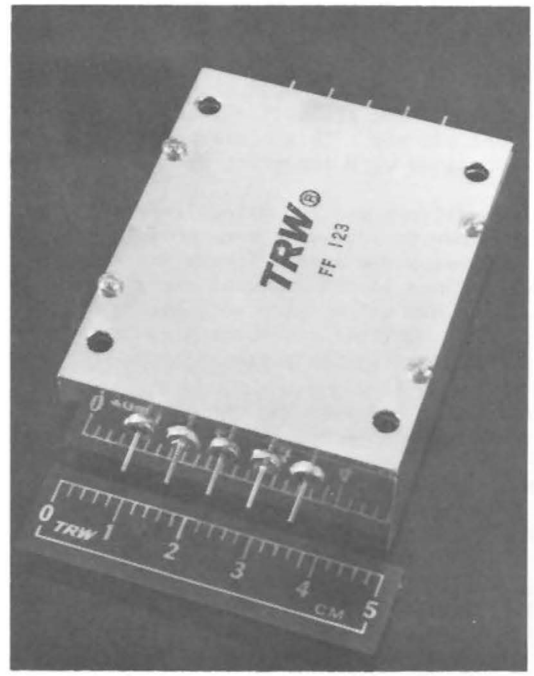


Figure 7. Photograph of Gain Block

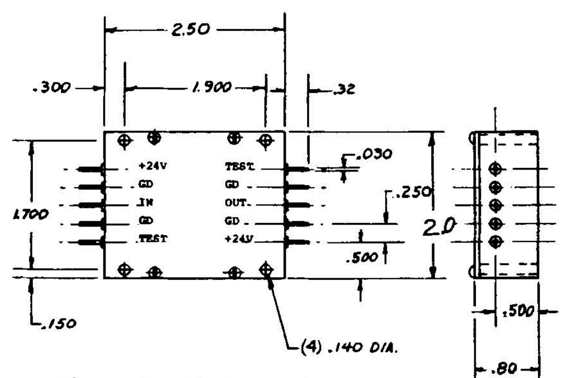


Figure 8. Package Dimensions

Construction

In anticipation of future frequency and gain increases, potential problems such as grounding and isolation have been given special care. The error and main amplifier substrates are mounted directly on the back plane (i.e., ground) of the feed-forward circuit. This minimizes the gain ripple associated with imperfect grounding.

The amplifiers and the delay lines are shielded from each other to achieve a very good isolation between RF paths, where signal levels are very different. Connections to the external circuit are made through input and output pins each surrounded by 2 ground pins. Circuit connections can be very short if a microstrip technique is used.

The package has been designed for a low thermal resistance between the transistors and the case. If the case temperature is kept below 100°C the temperature of the transistors is 135°C in the worst case. The mounting surface of the package is machined for good thermal contact with the amplifying station mainframe.

Circuit Realization

In order to achieve 450MHz bandwidth, the roll-off frequency of the main and error amplifiers used in a feed-forward circuit must be at least 500MHz. This is achieved by the use of transistors that have transit frequencies of typically 6GHz and very low parasitic capacitances.

The delay lines are printed in thin-film technique. The delays are 2.9 ns with losses of .25 and .75dB at 50 and 450MHz, respectively. Lumped delay lines have potentially less loss, but are more costly and are sensitive to temperature variations.

Extensive use of thin and thick film technologies on alumina substrates reduces the number and size of discrete and printed components. This increases the isolation between different parts of the circuit. Compact, microelectronic construction is expected to ensure long-term stability and reliability.

CONCLUSION

This paper describes the first generation realization of a feed-forward amplifier module. The integrated construction yields a compact, easy to use gain block. Performance and power consumption are similar to those found with discrete component realizations.

It is expected that the future will bring improvements in all areas. Specially designed microelectronic amplifiers will reduce the noise figure and increase the gain. At the same time the power consumption will be reduced. Single-ended and monolithic gain stages are expected to find use. In addition to being more efficient such amplifiers have less and more uniform delay than transformer-coupled circuits, as used in conventional hybrids. The bandwidth will follow the trends developing in the CATV Industry. There is no reason why feed-forward blocks could not reach 1GHz.

REFERENCE

G. Luettgenau and J. Powell - The Future of CATV Hybrids - Transactions of SCTE Conference, Boston, 1982.

A THEORETICAL EXAMINATION OF THE EFFECT OF A NONLINEAR DEVICE LOCATED AT A TAP

Thomas N. Lovern II* and Chalmers M. Butler**

*Comm/Scope Company
Catawba, North Carolina
**Department of Electrical Engineering
University of Mississippi
University, Mississippi

ABSTRACT

Intermodulation products represent a continuing concern to CATV system operators. In most systems, trunk amplifiers are designed to suppress first and second order intermodulation products. As a result, third order intermodulation products are of primary concern, especially with the increasing use of the 5-30MHz band. Due to the large number of frequencies carried by a typical CATV cable and the often indeterminate V-I characteristics of system nonlinearities, the amplitudes and frequencies of the intermodulation products are usually difficult to predict. It is advantageous, therefore, to understand the effects of nonlinearities in CATV systems and to be able to separate the contributions of amplifiers, connectors, taps, etc. in the overall frequency spectrum. In this paper, we consider, theoretically, the generation of intermodulation products at the junction of the seizure screw of the tap and the center conductor of the trunk line. In particular, the terminal response of a branched coaxial line with a nonlinear device located at the branch is discussed. In addition, the frequency spectrum present as a result of the excitation of the nonlinear device by the fundamental frequencies on the line is derived.

INTRODUCTION

The typical CATV system exists in an often harsh environment. The cable distribution system is usually an aerial array of trunk lines, amplifiers, taps, and drop cables subjected to large fluctuations in temperature, rain, ice, wind, and other damaging and corrosive elements. The electrical integrity of the system is, therefore, often difficult to maintain. Fortunately, a cause and effect relationship has been established for the majority of signal related problems. The consumer rarely fails to inform the CATV system operator of signal degradation and the cause is usually determined using a combination of on-site inspection and previous system experience. With the increasing use of the 5-30MHz band in two way systems, a more subtle but potentially harmful problem has arisen; namely, the generation of intermodulation products in the 5-30MHz band due to nonlinear junctions in the cable distribution system.

In this paper we first examine the V-I characteristics of nonlinear junctions and the generation of harmonics as a result of applying a time-harmonic excitation to the junction. Some measured data are presented and discussed in light of previous experimental work reported in the literature. The terminal response of a general transmission line is considered and equations are derived for a transmission line with a nonlinear device in series in the line. This model is extended to a branched coaxial cable with the nonlinear device located at the branch. A discussion of the meaning and application of the model follows.

FORMULATION

A junction (or device) is considered linear over a range ΔV (volts D.C.) if the corresponding current is such that Ohm's law is obeyed. Deviations from Ohm's law are indicative of a nonlinear junction. The V-I characteristic of a corroded junction formed by the seizure screw of a terminal block and the center conductor of a coaxial trunk line is shown in Fig. 1.

In order to analyze the frequency response of this junction, the V-I curve is fitted to a Taylor series given by

$$i = a_0 + a_1 v + a_2 v^2 + a_3 v^3 + a_4 v^4 + \dots \quad (1)$$

where $a_0=0$. For an ohmic junction, all coefficients a_n for $n \geq 2$ are zero. Applying a curve fitting routine to the curve in Fig. 1 yields the following coefficients.

$$a_1=0.28 \quad (2a)$$

$$a_2=0.00 \quad (2b)$$

$$a_3=-0.10 \quad (2c)$$

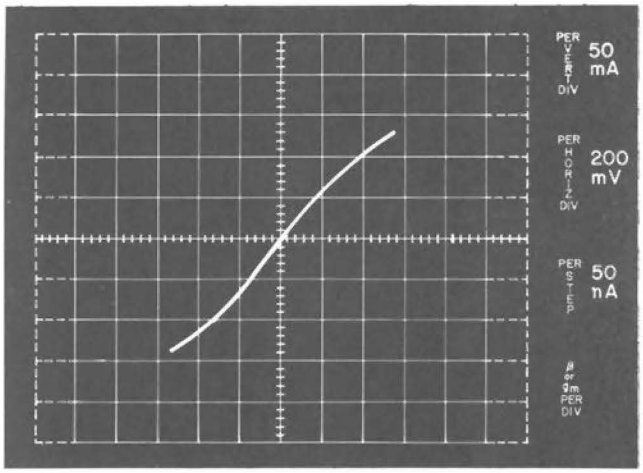


Fig. 1. Nonlinear V-I characteristic of a corroded junction.

where a_n for $n \geq 4$ are not significant. The zero value of a_2 indicates that the junction does not have any diode conduction characteristics while the value of a_3 indicates that the nonlinearity is due primarily to tunneling phenomena. This topic is discussed subsequently.

The generation of harmonics by a nonlinear junction is seen in a straightforward manner by applying a cosinusoidal excitation given by

$$v = V \cos \omega t \quad . \quad (3)$$

The general equation for the V-I characteristic of the nonlinear junction shown in Fig. 1 is given by

$$i = a_1 v + a_3 v^3 \quad (4)$$

where ω is the angular frequency ($\omega = 2\pi f$, where f is the frequency of operation).

Inserting (3) into (4) yields

$$i = a_1 V \cos \omega t + a_3 V^3 \cos^3 \omega t \quad (5)$$

and upon expanding the cube root, one obtains

$$i = a_1 V \cos \omega t + \frac{3}{4} a_3 V^3 \cos \omega t + \frac{1}{4} a_3 V^3 \cos 3\omega t . \quad (6)$$

Therefore, for an impressed voltage of angular frequency ω we obtain the fundamental ω and the third harmonic 3ω. As the number of fundamental frequencies on the line increases, the frequency spectrum, resulting from the junction's nonlinear response to the impressed voltage, becomes more complex. As an example, consider a cosinusoidal excitation with two fundamental frequencies.

$$v = V_1 \cos \omega_1 t + V_2 \cos \omega_2 t \quad (7)$$

In Table 1 the resulting frequencies and corresponding current amplitudes are shown for the excitation given by (7) impressed on the nonlinear junction represented by (3).

TABLE 1

Current Due to Voltage of Equation (7)

Frequency ($\omega = 2\pi f$)	Amplitude
ω_1	$a_1 V_1 + a_3 \left\{\frac{3}{4} V_1^3 + \frac{3}{2} V_1 V_2^2\right\}$
ω_2	$a_1 V_2 + a_3 \left\{\frac{3}{4} V_2^3 + \frac{3}{2} V_1^2 V_2\right\}$
$3\omega_1$	$\frac{1}{4} a_3 V_1^3$
$3\omega_2$	$\frac{1}{4} a_3 V_2^3$
$2\omega_1 - \omega_2$	$\frac{3}{4} a_3 V_1^2 V_2$
$2\omega_1 + \omega_2$	$\frac{3}{4} a_3 V_1^2 V_2$
$2\omega_2 - \omega_1$	$\frac{3}{4} a_3 V_1 V_2^2$
$2\omega_2 + \omega_1$	$\frac{3}{4} a_3 V_1 V_2^2$

Application of the results in Table 1 to two typical CATV channels, 2 and 6, yields the following frequency spectrum.

TABLE 2

Fundamental:	55.25MHz	
Fundamental:	83.25MHz	
Harmonics:	165.75MHz	193.75MHz
	249.75MHz	111.31MHz
	27.22MHz	221.75MHz

Clearly, for a typical CATV system with as many as 35 channels, a large number of harmonics could fall in the 5-30MHz band.

Network Equivalent Of A Transmission Line

A length ℓ of coaxial cable operating in the TEM mode can be modeled by a two-wire line equivalent and therefore a two-port equivalent network. Assume a load Z_L to exist at port 2 and a driving source voltage v to exist at port 1. The transmission-line equivalent is given in Fig. 2a. The corresponding network equivalent is shown in Fig. 2b.

The network equivalent of Fig. 2b allows one to relate V_1 and V_2 to the currents I_1 and I_2 by the impedance matrix.

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} \quad (8)$$

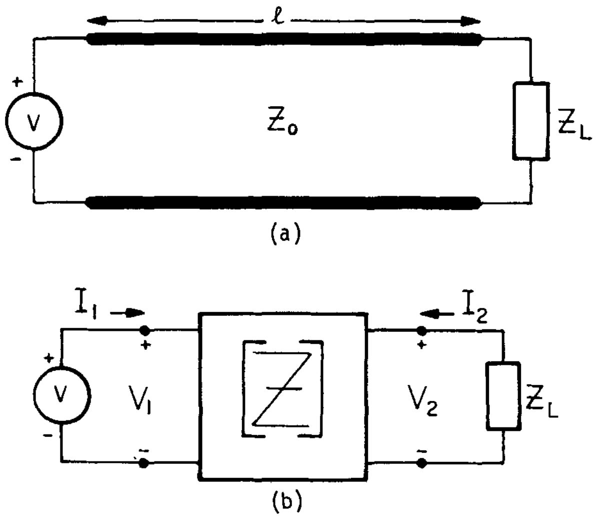


Fig. 2. (a) Two-wire line equivalent of a coaxial cable. (b) Two port network equivalent of (a).

where $V_1=v$ and $V_2=-I_2 Z_L$. I_1 and I_2 are easily obtained by inverting $[Z]$ and computing $[Z]^{-1}[V]$. For reference, the matrix $[Z]$ is given by

$$[Z] = -jZ_0 \begin{bmatrix} \cot k\ell & \dfrac{1}{\sin k\ell} \\ \dfrac{1}{\sin k\ell} & \cot k\ell \end{bmatrix} \tag{9}$$

where Z_0 is the characteristic impedance of the coax (and the equivalent line). Note that the matrix elements are frequency dependent, i.e.

$$k\ell = 2\pi\left(\frac{\ell}{\lambda}\right) \tag{10}$$

where λ is the wavelength. This matrix representation is useful for computations and visualization of interactions which may take place in more complicated networks.

Now consider the simple circuit shown in Fig. 3.

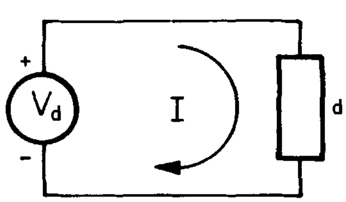


Fig. 3. Simple circuit with a nonlinear device excited by a voltage source.

The device, 'd', is the nonlinear junction considered in Fig. 1 and modeled by eq. 4 where the sign of a_3 has been explicitly indicated. Assuming

$$\left|\frac{3}{4} a_3 V_d^3\right| << \left|a_1 V_d\right| \tag{11}$$

which holds in typical practical cases, one reduces eq. 6 to

$$i \approx a_1 V_d \cos \omega t - \frac{1}{4} a_3 V_d^3 \cos 3\omega t \tag{12}$$

Now consider Fig. 4a. This circuit consists of a voltage source v, the nonlinear 'device', and a frequency dependent load $Z_L(\omega)$. The cosinusoidal excitation v is given by eq. 3. Fig. 4b is an approximate equivalent circuit with a dependent current source at frequency 3ω and with an output proportional to V_d^3.

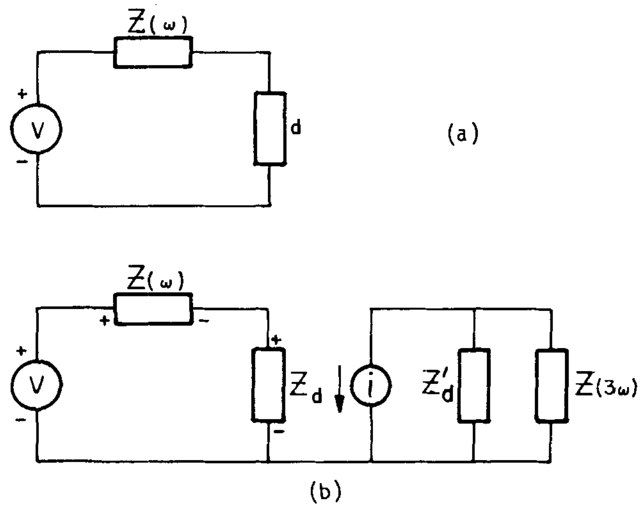


Fig. 4. (a) Simple circuit with a nonlinear device and load excited by a voltage source. (b) Equivalent circuit for (a) with dependent current source.

Z_d represents the impedance of the device due to the linear 'component' of eq. 12 ($1/a_1$). Z_d' represents the impedance of the nonlinear 'component' of eq. 12.

From Fig. 4b a voltage equivalent circuit, shown in Fig. 5, can be constructed where v_g is proportional to V_d^3. It is an approximate equivalent circuit because the dependent source V_3 is assumed to be a perturbation and I is assumed to be independent of I_3. It is possible to compute the currents I and I_3 and to arrive at the total current shown in Fig. 4b by adding the results together. The impedance Z in the right-hand side of Fig. 5 assumes its value at 3ω. If this impedance contained a contribution from a transmission line then that line would have an electrical length three times that of its value in $Z(\omega)$ in Fig. 5.

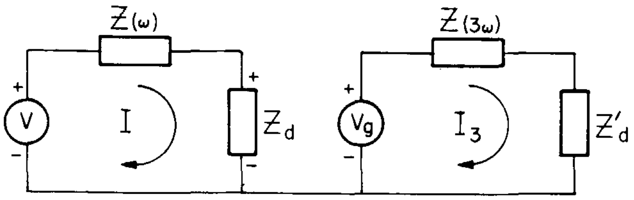


Fig. 5. Approximate equivalent circuit for Fig. 4b with dependent voltage source.

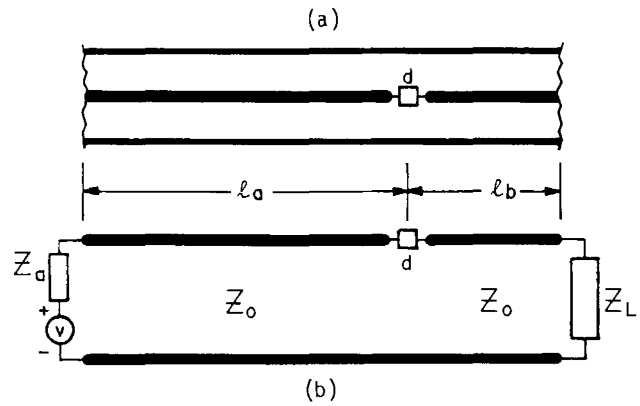


Fig. 6. (a) Coaxial line segment with a nonlinear device in series. (b) Transmission line equivalent of (a).

Network Equivalent For A Nonlinear Junction In Series With Coaxial Lines

Fig. 6a shows a segment of coaxial line with a nonlinear device in series in the line. Such a situation could arise in pin type or splice connectors where the center conductor is grabbed by the seizing mechanism. Fig. 6b is the transmission line equivalent with a voltage source v, Z_a which consists of the generator impedance and any other sections of line and load impedance Z_L. The characteristic impedance of the coax is Z_0 and the junction 'd' is located a length ℓ_a from the generator.

A network equivalent can be constructed on the basis of the concepts developed in previous sections. The network equivalent of the circuit shown in Fig. 6b is

The upper part of Fig. 7 is the network that operates at frequency ω (first harmonic). $[Z^A]$ and $[Z^B]$ are the impedance matrices for cable lengths ℓ_a and ℓ_b. All of the impedance elements must be evaluated at ω. Z_d is the first harmonic impedance of the junction. The lower part of Fig. 7 is the network that operates at frequency 3ω. The third harmonic values of the elements of the impedance matrices, $[Z^A]$ and $[Z^B]$, are now used in the calculation, Z_d' is the third harmonic impedance of the junction. Note that v does not appear in this network, since its impedance is that of a short circuit. The new (dependent) generator appears at the junction location and generates a voltage V_3 which is proportional to V_d^3. To compute, for example, the total current through the load Z_L in Fig. 6b, one first would compute the current through $Z_L(\omega)$ from the upper part of Fig.7 and then the current through Z_L (3ω) from the lower part of Fig. 7 and add the two together. Note that the voltage V_3 depends upon V_d^3 which implies that, if the input voltage v is changed, then the voltage in the lower circuit does not change proportionately. That is if v is, for example, doubled, the currents and voltages in the lower circuit will not double.

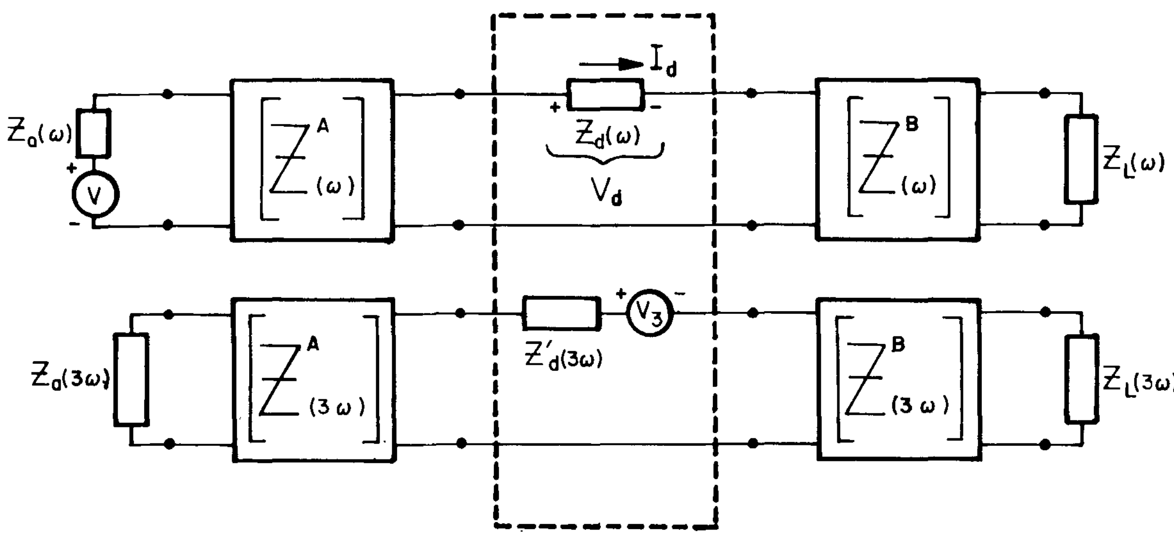


Fig. 7. Network equivalent of the circuit shown in Fig. 6b.

Network Equivalent For A Branched Transmission Line With A Nonlinear Junction At The Branch

Fig. 8a shows a branched coaxial transmission line with a nonlinear junction located at the branch. This branched structure commonly occurs at a tap. The nonlinear junction could arise due to corrosion or the presence of other thin insulating films between the trunk line center conductor and the seizure screw and terminal block. This effectively places the nonlinear junction in series with the branched line (normally a drop cable). Fig. 8b is the transmission line equivalent with a voltage source v with impedance Z_a and a load impedance Z_L. The branch is a distance ℓ_a from the generator and has a length ℓ_c with load impedandce Z_c. The nonlinear junction is labeled 'd'.

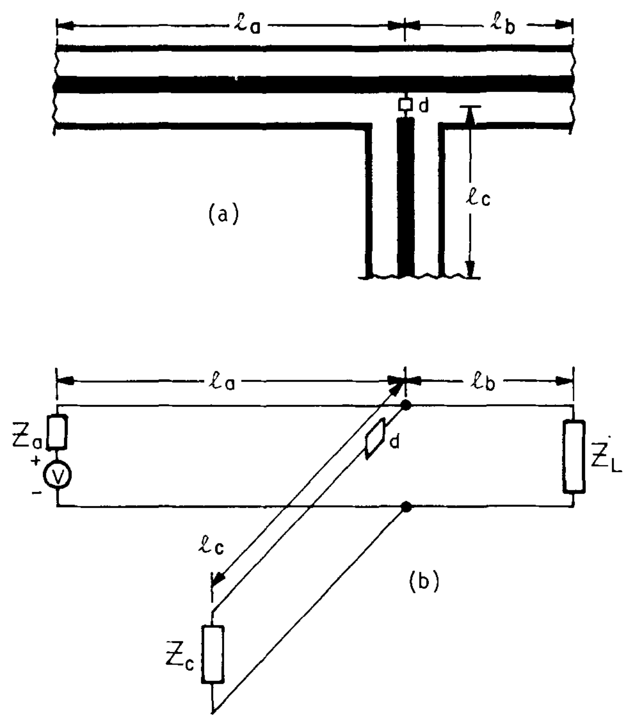


Fig. 8. (a) Branched coaxial line with a nonlinear junction at the branch. (b) Transmission line equivalent of (a).

Extending the results of the previous section, one can construct a network equivalent of the transmission line equivalent shown in Fig. 8b. This is shown in Fig. 9.

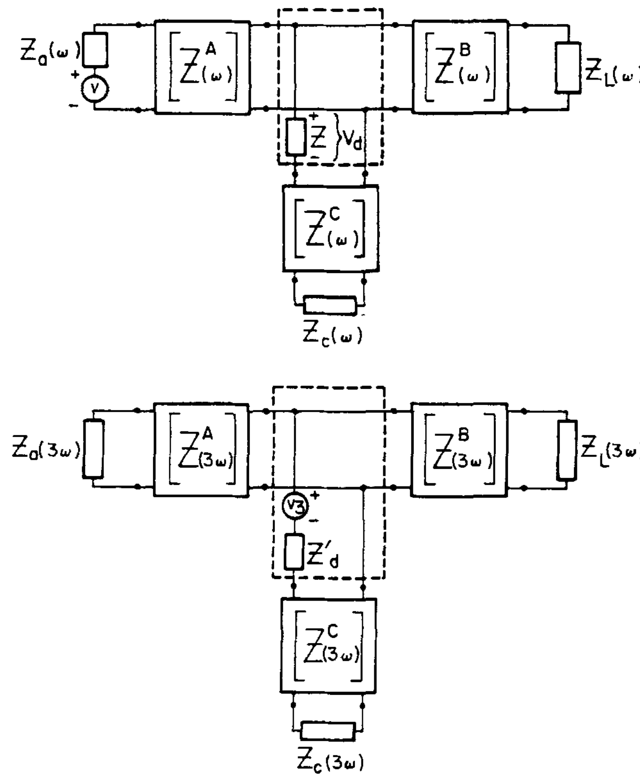


Fig. 9. Network equivalent of the circuit shown in Fig. 8b.

The concepts used in evaluating terminal currents and voltages in this network are identical to those used to evaluate similar quantities of the nonlinear junction in coaxial lines. The upper part of Fig. 9 is the first harmonic 'component' with all impedances evaluated at frequency ω. The lower part of Fig. 9 is the third harmonic 'component' with all impedances evaluated at frequency 3ω. The generator V_3, in the lower part, operates at a frequency 3ω and has an output proportional to V_d^3. The total current is the sum of the currents in the upper and lower parts.

DISCUSSION

The network equivalents presented for a junction in series in a coaxial line and a junction at a branch in a coaxial line allow one to calculate, using standard network theory, the currents and voltages present as a result of the excitation of the nonlinear junction. The junction is assumed to generate only the fundamental and the third harmonic. In actual practice, a cable system contains many 'fundamental' frequencies each of which may be modulated. This spectrum or frequencies, upon interaction with the nonlinear junction, will result in the generation of an enormous number of harmonics, even for a junction that can be described by a simple equation such as (4). For example, the excitation given by (7) would result in six additional frequencies present in the system. In the case of the network equivalent shown in Fig. 10, there would be two calculations for the upper network; one at frequency ω_2. All the impedances would assume their values at the respective generator frequency. Similarly there would be a calculation for the lower network at each of six different frequencies: $3\omega_1$, $3\omega_2$, $2\omega_1-\omega_2$, $2\omega_1+\omega_2$, $2\omega_2-\omega_1$ and $2\omega_2+\omega_1$. Each dependent generator would have a different voltage amplitude and, again, all impedances would assume their values at the respective generator frequency. To calculate the current through any particular load, one would sum the currents from these eight computations. Clearly, the extension to a more complex frequency spectrum would involve straightforward but very lengthy calculations.

The presence of the cubic term and the absence of the square term (along with terms of order higher than cubic) is given as justification for assuming that the nonlinear response of the junction is due to tunneling of electrons through an insulating film separating the metal surfaces. This observation is supported numerous times in the literature [1-5]. In general, a junction's V-I characteristic has been found to be extremely pressure sensitive. In particular see reference (5). It would not be unreasonable to envision a junction that was linear at one time of the day, becoming increasingly nonlinear as the temperature fell during the afternoon. The associated generation of harmonics would follow. Similarly, stress relaxation at metal contacts could also reduce contact pressure with the possibility of the formation of a nonlinear junction. Corrosion of any type would only aggravate the situation.

SUMMARY

In this paper the V-I characteristics of nonlinear junctions and the generation of harmonics by these junctions when a time-harmonic excitation is impressed upon them is discussed. Equivalent circuits are presented for nonlinear junctions that are in series with and at a branch between coaxial lines. From these circuits, network equivalents are constructed which allow one to calculate the terminal voltages and currents using standard network theory. It is pointed out that the nonlinear junctions typical in CATV cables and connectors are probably due to tunneling phenomena.

REFERENCES

1. Higa, W.H., "Spurious signals generated by electron tunneling on large reflector antennas, "Proc. IEEE, vol. 63, no. 2, pp.306-13, Feb. 1975

2. Bayrak, M. and Benson, F.A., "Intermodulation products from nonlinearities in transmission lines and connectors at microwave frequencies," Proc. IEE, vol. 122, no. 4, pp. 361-7, April 1975

3. Betts, J.A. and Ebenezer, D.R., "Intermodulation interference in mobile multiple-transmission communication systems operating at high frequencies (3-30 MHz)," Proc. IEE, vol. 120, no. 11, pp. 1337-44, Nov. 1973

4. Arazm, F. and Benson, F.A., "Nonlinearities in metal contacts at microwave frequencies," IEEE Trans. Electromagn. Compat., vol. EMC-22, no. 3, pp. 142-9, Aug. 1980

5. McMillan, M.R., "Non-linear junction characterization," Tech. Note no. 79-7, Dept. National Defense Canada, May 1979

ADVANCED HYBRIDS FOR CATV AMPLIFIERS

Jay G. Staiger

Magnavox CATV Systems, Inc.
100 Fairgrounds Drive, Manlius, NY 13104

Improvements in hybrid I.C. amplifiers from applications of superior impedence matching and thermal design techniques result in a cost effective means to achieve better noise and distortion performance for a CATV Distribution System. When implemented in a CATV design, several benefits can be realized:

1. Longer trunk cascades.
2. Higher trunk gains.
3. Expand existing bandwidth - 270-450 MHz.
4. Eliminate expensive hub architectures.
5. Eliminate expensive distortion cancelling techniques.

The CATV Industry has been demanding higher levels of performance from CATV distribution systems. Increased channel loading requirements to cover large areas, competition from a large number of high quality, local, off-air signals, and the economics of system architectures are reasons for the need to increase performance from a CATV amplifier.

As bandwidths expanded and were loaded in excess of 58 television channels, the tolerable trunk cascades were shortened. The trunk system which was designed to be typically transparent, became less transparent, and contributed significantly to the total system distortions. To compensate for the decreased transparency of the trunk, the bridger and line extender levels, along with the higher cable attenuation, significantly increased the initial and ongoing costs of the CATV distribution system.

Techniques such as harmonically related headends were applied to off-set some of the reductions in system trunk reach and lower feeder levels. However, these systems had to deal with the different problems. The trend now is to avoid harmonically related systems and stay with standard channel assignments, if at all possible.

The most demanding force for the higher CATV distribution system performance is the specifications required by the franchiser.

There is another technology which is available, and most importantly, is cost effective. It is cost effective because it can be used to do one or more of the following:

1. Eliminate multiple hub requirements.
   a. No duplicate headend processors.
   b. No duplicate tower antennas.
   c. Reduced microwave interconnect expense.
2. Eliminate HRC requirements.
3. Can be applied in place of feedforward techniques.
4. Reduce the number of amplifiers of the CATV distribution system Bill-of-Materials.
5. Reduce bandwidth expansion costs in existing plant.

This technology can be used to realize one or a combination of the above savings depending on the franchise requirement specifications, and system topology when a high performance amplifier is applied.

The Objective- The initial goal was to develop a technology that improves distortion and noise performance within the confines of the existing amplifier packages and to maintain the standard size of the hybrid amplifier. The paramount criteria is that it should be cost effective.

After months of careful documented research, Magnavox CATV Systems, together with its North American Philips' sister company, Amperex, has developed a significant technological breakthrough that met our goal. This breakthrough is called Power Doubling.

The heart of the Power Doubling system is the postamplifier with improved distortion parameters. The system utilizes precise impedence matching, optimized frequency response flatness, and superior thermal design that permits a much higher output from the single hybrid package. All these factors combined, provide a minimum of a 6 dB improvement in composite triple beat and cross mod specifications when compared to a conventional hybrid system

In addition, a low noise preamplifier has been introduced to the system so that excellent noise performance can be realized. This preamplifier allows the Magnavox Power Doubling product to have at least a 2 dB better noise figure than that available with other hybrids.

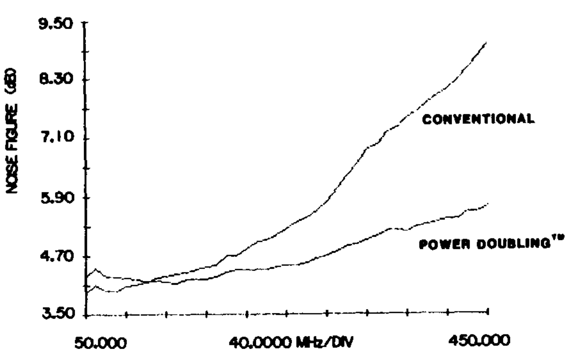
The above stated improvements will be the minimum achievable. Some of the data accumulated indicated that, typically, we can expect greater improvements. The subsequent text and illustrations will show greater than 3 dB improvement in noise figure and approximately 6.5 dB improvement in distortion. The two components which make-up the Power Doubling system, the low noise preamplifier and the power doubler postamplifier are configured so that it is packaged for use with Magnavox's present product line. This makes it extremely cost effective and provides the operator with equipment for an advanced system architecture at an affordable price.

<u>Test Results</u>- Testing completed on the initial product proves the performance is as expected. Figure #1 is a graph of noise figure vs frequency, and is plotted from 50 MHz to 450 MHz. It indicates an improvement in the worst case noise figure at 450 MHz of 3.3 dB.

FIGURE 1

UNIT NOISE FIGURE

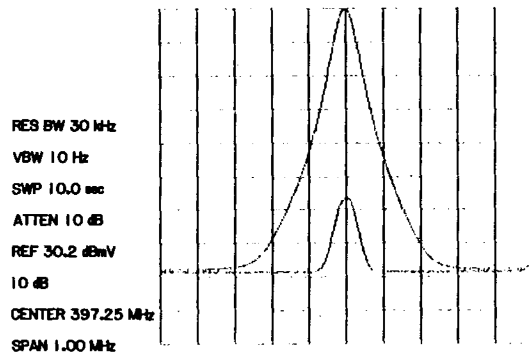
CONV. VS P.D.



Test results for composite triple beat also show the expected results. Comparing Figure #2a with Figure #2b shows a 6.5 dB improvement in composite triple beat. Figure #2a is the conventional hybrid and measures -55.6 dB carrier-to-composite triple beat ratio. This figure illustrates a spectrum analyzer display with a CW carrier superimposed over the composite triple beat distortion. Figure #2b is a display of the carrier-to-composite triple beat ratio of the <u>power doubling</u> amplifier and measures a 63.1 dB carrier-to-composite triple beat ratio. Take note that the CW carrier levels for both Figure #'s 2a & 2b are equal, but the distortion is 6.5 dB lower in the power doubling case.

FIGURE 2a

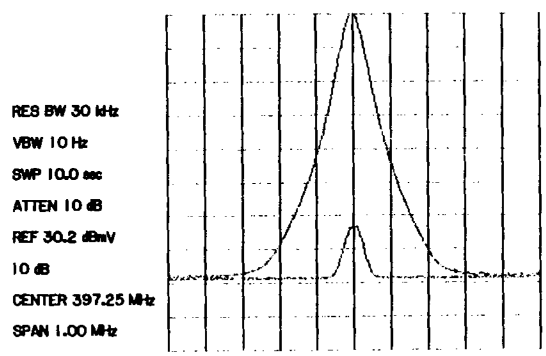
UNIT C/CTB - CONVENTIONAL



CONVENTIONAL 5-T440 W/58 CH. AT 46 dBmV (-55.6 dB)

FIGURE 2b

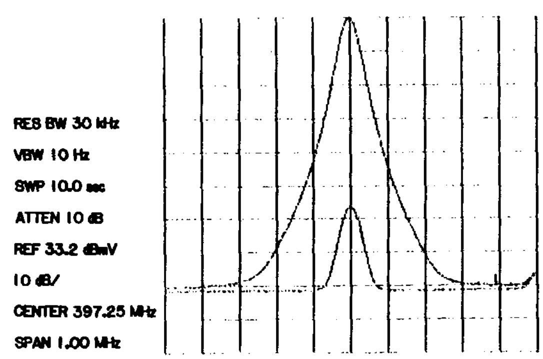
UNIT C/CTB - POWER DOUBLING™



POWER DOUBLER 5-T440 W/58 CH. AT 46 dBmV (-63.1 dB)

FIGURE 2c

UNIT C/CTB - POWER DOUBLING™
AT 3dB HIGHER OUTPUT



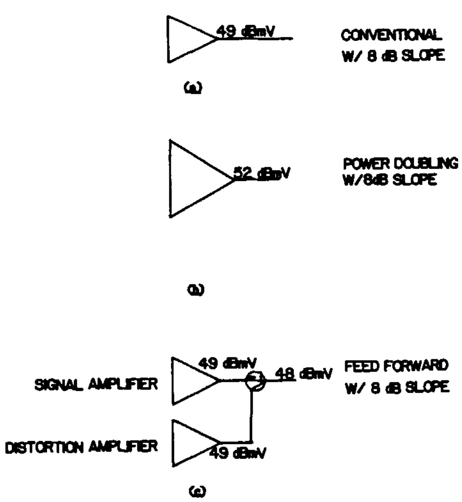
POWER DOUBLER 5-T440 W/58 CH. AT 49 dBmV (-56.1 dB)

To confirm this measurement, and also to prove that the third order peformance is behaving as expected on a 2 dB of distortion for 1 dB of output level change, the output level of the power doubling amplifier has been increased by 3 dB and is shown in Figure #2c. Take note that the carrier-to composite triple beat ratio measures -56.1 dB and is still .5 dB better than the conventional hybrid amplifier.

Summarizing the distortion test results, we can say that the amplifier has double the power output (a 3 dB increase is equal to twice the power) when compared to the conventional hybrid for approximately the same level of distortion.

Compression Point- For the purpose of the discussion in this paper, I am defining the compression point as the output level of the CATV amplifier where the change in distortion (take note that I do not say composite triple beat distortion) deviates from a 2 dB in composite beat for 1 dB of output level change, to a 3 dB of composite beat for 1 dB of output level change. Refer to Figure #3 for a comparison of the compression points for conventional, power doubling and feedforward amplifiers. Figure #3a is the conventional hybrid and shows a compression point of 49 dBmV. Figure #3b shows a Power Doubling amplifier having a 52 dBmV compression point or a 3 dB improvement over the conventional hybrid compression point.

FIGURE 3



Comparing feedforward technology to power doubling technology you will note that there is a 4 dB better compression point for the power doubler; the feedforward having 48 dBmV vs 52 dBmV of power doubler. Also note that a standard conventional hybrid has a 1 dB better compression point. The reason for the lower compression point of the feedforward amplifier is the fact that the signal output from the hybrid I.C. amplifier must pass through the combiner where the distortion cancellation takes place. This output combiner, for this illustration, is assummed to have 1 dB of insertion loss and results in a 1 dB degradation in the compression point.

During the system design planning process, when the engineer calculates the amplifier operating levels and the resulting system performance, he must consider the compression point of the amplifier. For a standard CATV hybrid loaded to 450 MHz, the output level should not exceed 50 dBmV. Likewise, I have noted system designs utilizing feedforward technology which are limited to 49 dBmV maximum operational output level. The power doubling amplifier, however, since it does have the improved compression point, can operate up to approximately 53 dBmV. In CATV systems with up to approximately 20 amplifiers in cascade, the power doubling, bridger amplifier and line extender amplifiers will be able to operate at higher levels, thus reducing the number of amplifiers required when compared to feedforward technology. A lower number of amplifiers means less initial expense, and less ongoing operational expense.

Longer Cascades and Extended Trunk Reach- At this point, I would like to restate the increase of performance for the power doubler in terms of dynamic range. The increase in dynamic range of the amplifier is 5 dB. That is the combination of the improvement in noise figure and the improvement in output levels:

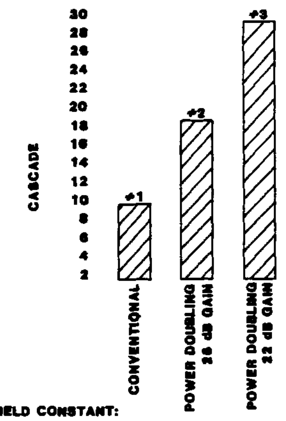
$$\text{Improved Dynamic Range} = \Delta\,\text{Noise Figure} + \Delta\,\text{CTB}/2$$

$$5\ \text{dB} = \Delta 2 + \Delta 6$$

This 5 dB increase in Dynamic Range will yield the improvements in cascadability that is shown in Figure #4. Three columns are shown. Column #1 indicates a conventional system at approximately 10 amplifier maximum cascade; the second column shows a power doubling amplifier at 26 dB gain and results in an approximate 20 amplifier maximum cascade; the third column depicts a power doubling amplifier at 22 dB gain and indicates an approximate 30 amplifier cascade. At the end of each of these cascades, the resulting system performance, in terms of carrier-to-noise and carrier-to-composite triple beat, are identical. This is to say, the power doubling column at 22 dB gain, will meet a 47 dB carrier-to-noise and 53 dB carrier-to-composite triple beat at the end of 30 trunk amplifiers, plus 1 bridger, plus 2 line extenders in cascade. This is an improvement of three times the system reach over the conventional system.

FIGURE 4

TECHNOLOGY VS. CASCADE COMPARISON



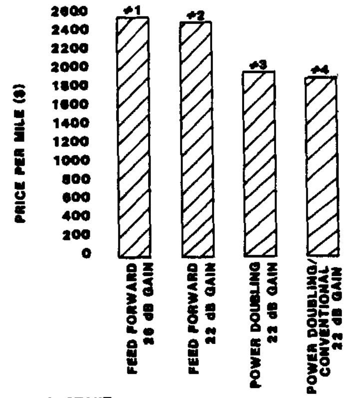
HELD CONSTANT:

FREQUENCY	440 MHz
CHANNEL LOADING	58
TRUNK SPACING	22 dB
BRIDGER OUT	46 dBmV
LINE EXTENDERS (2 IN CASCADE) OUT	42 dBmV
SYSTEM C/N	47 dB
SYSTEM C/CTB	-53 dB

FIGURE 5

PRICE PER MILE COMPARISON

(ACTIVE ELECTRONICS)



HELD CONSTANT:

FREQUENCY	440 MHz
CHANNEL LOADING	58 CHANNELS
DESIRED SYSTEM C/N	47
DESIRED SYSTEM C/CTB	-53
LONGEST CASCADE	29 at 22 dB trunkspacing 25 at 26 dB trunkspacing

As a result of the improved cascadability with power doubling, the cable TV operator can take advantage by reducing the number of hubs necessary to build a given CATV system; or, where critical specifications need to be met, power doubling can be used in lieu of feedforward technology. For example, if the specifications in Figure #4 were to be met at 29 amplifiers in cascade, a conventional system could not be used. Therefore, the choice would be either feedforward or power doubling to meet these specs.

Cost Effectiveness- In order to prove the cost effectiveness in systems where conventional amplifiers could not fulfill the specification requirements, a series of study designs were performed. A sample area was selected and consisted of approximately 25 miles of CATV distribution system. The performance specs. given in Figure #5 are held constant in each of the designs. The results of the study designs are plotted in Figure #5. Take note that the feedforward technology, shown by columns 1 and 2, priced out at approximately $2500.00 per mile. Comparing that to columns 3 and 4, which is the power doubling design, it priced out at approximately $1900.00 per mile, or approximately $600.00 less for power doubling.

To reiterate, it was determined that this system required approximately 29 amplifiers in cascade at 22 dB trunk spacing. It was determined by Figure #4 that the conventional technology can only meet those specifications up to 10 amplifiers in cascade. Therefore, it was concluded that either feedforward or power doubling need to be used. Now the judgment would be purely economic because the specifications could be met by both power doubling and feedforward. Based on economics of the study designs, the choice would obviously be for power doubling at $600.00 less per mile. Futhermore, I would like to put this savings into perspective. State-of-the-art CATV distribution systems now being proposed are usually a minimum of a dual subscriber system. In a dual cable subscriber system, this $600.00 a mile savings would have to be doubled for a total of $1200.00 a mile savings. If this was a 1000 mile system, the total initial cost savings would be $1.2 million dollars.

A cost savings can be illustrated in a different manner. For example, if the same system requiring a total of 30 amplifier cascades could be designed with conventional equipment and 2 hubs, the additional cost would result from the addition of 1 hub and all the associated equipment. If power doubling could be used to eliminate 1 of those hubs, the expense of an additional 58 channel headend, tower and antennas, earth station equipment, real estate, two-way microwave connection between hubs, and the associated ongoing operating costs could be eliminated.

Eliminate The Harmonically Related Signal Requirement- Harmonically related carrier systems (HRC) have been applied in expanded bandwidth systems to improve the subjective picture quality of the TV signals. Some people believe that there are sufficient technical reasons why HRC headends should not be used. Other people believe that the problems created through the use of HRC are outweighed by the subjective improvements. In a situation where the technical disadvantages are perceived the power doubling amplifier can be used to make up for the HRC benefit. In either case, the HRC headend is somewhat more expensive than headends applying standard frequency assignments. In these situations, the Power Doubling concept can be used to save the additional cost for the HRC headend.

It is felt that the general consensus for an HRC improvement is approximately equivalent to 6 dB of carrier-to-composite triple beat. For example, if a system was designed for a 53 dB carrier-to-composite triple beat ratio with standard frequency assignments, that same system with HRC could be designed for a 47 dB carrier-to-composite triple beat ratio, or a 6 dB reduction in the spec. This would yield the same picture quality for both the standard channel assignments and the HRC channel assignments.

Since the power doubling amplifier improves the distortion of a conventional amplifier by 6 dB, this improvement can be directly applied and compared to the 6 dB improvement of the HRC system. Therefore, a standard headend could be installed, along with power doubling amplifier systems, resulting in the same distribution system design architecture and bill-of-materials, but eliminating the need for harmonically related signals.

Drop-In Bandwidth Expansion- Another major benefit of a power doubling product is its ability to be applied for existing system bandwidth upgrades. Because of the significantly increased dynamic range of the product and, because it will be available with operational gains up to 27 dB, a 270 MHz distribution system can be upgraded to 450 MHz with 60 channel loading. This can be accomplished by directly dropping in the power doubling modules at existing trunk amplifier locations. There will be no need to move trunk amplifier locations. As indicated previously, the goal for this product was that it be housed identically to the Magnavox existing product. This means that existing Magnavox systems only need to swap out trunk modules and bridger modules. Housings, connector chassis and return modules can remain unchanged (if 270 MHz is to be expanded to 440 MHz, the model series 5-MC-2 chassis must be installed in the existing equipment).

With the conventional equipment, an upgrade from 270 to 450 MHz would require the complete redesign and respacing of the entire CATV distribution network. This would be more costly than the original initial build. The drop-in capability of power doubling provides a significant cost

SUMMARY

A net 5 dB improvement in dynamic range, as a result of a minimum of 2 dB better noise figure and 6 dB better distortion performance, is provided. Savings in CATV distribution systems design can be realized by reduction in actives, reduction in the number of hubs and elimination of the need for feedforward technology. Improved technical performance can be realized by eliminating the need for harmonically related carrier systems or by just applying the increased dynamic range for purposes of having sufficient head room on the subjective performance of the TV picture signal.

It should be noted that every CATV distribution system has its own unique features and design requirements. The examples presented here were based on certain assumptions. Magnavox's Systems Engineering Department can provide an analysis of your specific case to determine the benefits as they may apply.

Please stop by Booth #1502 at the 1983 NCTA, or write Magnavox CATV Systems, Inc., 100 Fairgrounds Drive, Manlius, NY 13104

AN OFF-PREMISES CONVERTER WITH MULTIPLE SIGNAL PATHS

Charles M. Palmer
Engineering Manager of Digital Products Group

C-COR ELECTRONICS, INC.
State College, Pennsylvania

ABSTRACT

An off-premises converter with controllable multiple signal paths fixes the problems inherent with the simple off-premises converter. The unconverted path solves the additional set problem. The reverse path allows for future two-way communications. These with the converted path provides an off-premises unit that meets the needs of todays cable systems.

INTRODUCTION

Several years ago, C-COR managers decided to fill a large market niche existing for off-premises addressable converters. These units, we believed, would solve many problems plaguing the converter market. Signal and equipment theft; equipment access and control; these were to be wiped out in one fell swoop.

Our orginal design was a simple off-premises converter consisting of a box on a pole. The box contained a power supply, tuner, microcomputer controller, and data link for addressable control.

The road to this basic converter was rocky and seemingly endless. Meeting tuner and other component specifications in temperature extremes of −40 to 60 C wasn't easy. Keeping the electronics protected against Mother Nature's tricks of moisture and lightning was just as difficult. Designing a highly reliable product that functions under widely varying operating conditions, while satisfying the Underwriters Laboratory, is an experience that I wish on no one.

Problems With Off-Premises Converters

Meeting UL codes and coping with the weather were solvable problems; the technology was at hand. But that didn't help us. We had the wrong product for the market. People wanted choice, and our simple off-premises converters delivered only one channel at a time to all sets of a multiple-set customer (the "additional set" problem). To solve this problem, we could put additional converters on the pole. Sounds simple, but the additional wiring needed for each pole-mounted converter and the extra converters themselves boosts costs to unrealistic heights. That wasn't all. The simple off-premises connverter had no reverse path (5 – 30 MHz), and that was unacceptable.

A SOLUTION

We chose to employ multiple signal paths into and out of the home on one cable drop. The design included: The converted (to Channel 3 or 4) signal path into the home, the unconverted signal path for additional sets, and the reverse signal path for future two-way operation. All paths are controlled by the off-premises unit (Figure 1). A description of our system follows.

A Component Overview

The system consists of four components. These are the SCAT-TAP, the SCAT-CAN Series 10, the Power Pack, and the Keypod. The SCAT-TAP is a tap unit — a mounting fixture for four SCAT-CANs — and provides some signal security. The SCAT-CAN Series 10 is the addressable off-premises unit that contains the converter and controls all signal paths into and out of the home. The Power Pack provides AC power to the SCAT-CAN and DC power to the Keypod; it also passes the low-frequency control signal from the Keypod onto the coax and up the drop to the SCAT-CAN. The Keypod is a requesting device that the customer uses to select a channel. The SCAT-TAP and SCAT-CAN are on the pole; the Power Pack and Keypod are in the home.

The Converted Signal Path

The converted signal path operation begins as the customer selects a channel on the Keypod. The Keypod then transmits the channel request to the SCAT-CAN using a 40 kHz carrier with on/off keying (OOK) modulation. A microcomputer in the SCAT-CAN receives the carrier and digitally demodulates it (Figure 2 — line type 6). The microcomputer looks in the customer authorization table in nonvolatile RAM to see if the customer may watch the requested channel. Assuming that the customer is cleared, the microcomputer looks in a ROM table to locate the required frequency and cable for this channel. The microcomputer then tunes the converter using a digital phase-locked loop control circuit and selects the appropriate cable (Figure 3 — line type 7). As with set-top converters, the converted signal must be viewed by tuning the set to Channel 3 (Figure 2 — line type 5). If the customer is not permitted to watch the requested channel, a promotional channel will be tuned. The authorization table is sent by the control computer via an RF data carrier with frequency-shift-keying (FSK) modulation (Figure 2 — line type 4). The data signal is always on cable A.

This operation is similar to the original simple off-premises converter.

The Unconverted Signal Path

Cable A carries the unconverted signal. It is filtered to pass only the non-premium signals (50 - 216 MHz), and is amplified to match the signal level out of the converter. This unconverted signal is controllable via the microcomputer. The microcomputer either allows this service to pass into the home or terminates this path by selecting the position of an RF switch. Unconverted and converted paths are then combined and sent down the drop into the home (Figure 2 — line type 3). Since these paths have overlapping frequency ranges, the unconverted path cannot have a signal at Channel 3. An adequate filter to remove Channel 3 from the unconverted signal path would be very expensive; therefore no signal can be carried on cable A at the Channel 3 frequency. A 20 dB Channel 3 band-stop filter in the unconverted path is added to reduce noise that might degrade the converted signal.

The unconverted signal path solves the additional set problem inherent in a simple off-premises converter. This signal path allows customers to choose different shows on different sets and carries the FM

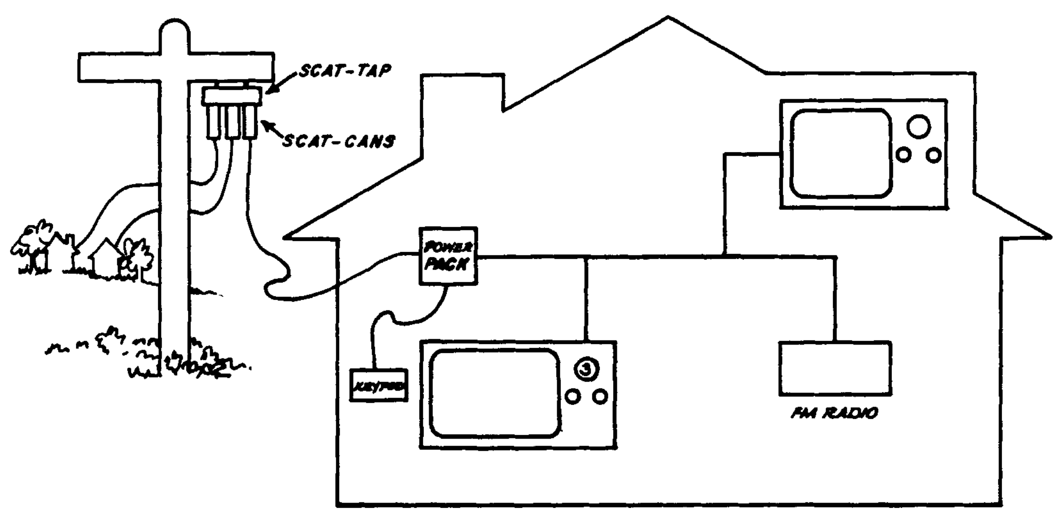


FIGURE 1

radio band. Customers may watch any of the 11 channels of unconverted signal on a normal TV set or may use a block converter or a cable-ready TV to pick from 20 channels. Unconverted signals are either on or off; there is no individual channel control. The customer may watch a converted signal (premium service) by tuning his or her TV to Channel 3 and using the Keypod to select the channel. All sets in the house may be used to view this converted signal; all sets receive the same signals. Only one converted signal may be viewed at a time.

The Reverse Signal Path

The reverse signal path comes from the house into the SCAT-CAN. This signal is separated from the forward path by a diplex filter, controlled by an RF switch, and recombined onto the cable A input using another diplex filter (Figure 2 — line type 1). The microcomputer controls the RF switch, but does not "talk" in the reverse direction (back to the controller). By controlling the reverse signal path, the system operator can turn off the reverse path where it is not needed. This helps stop ingress. The reverse signal path along with the unconverted forward path permits future two-way communications with the home, without replacing or upgrading the off-premises unit.

CONCLUSION

An off-premises addressable unit can be configured to overcome the basic conceptual problems inherent in a simple off-premises converter. An ad-

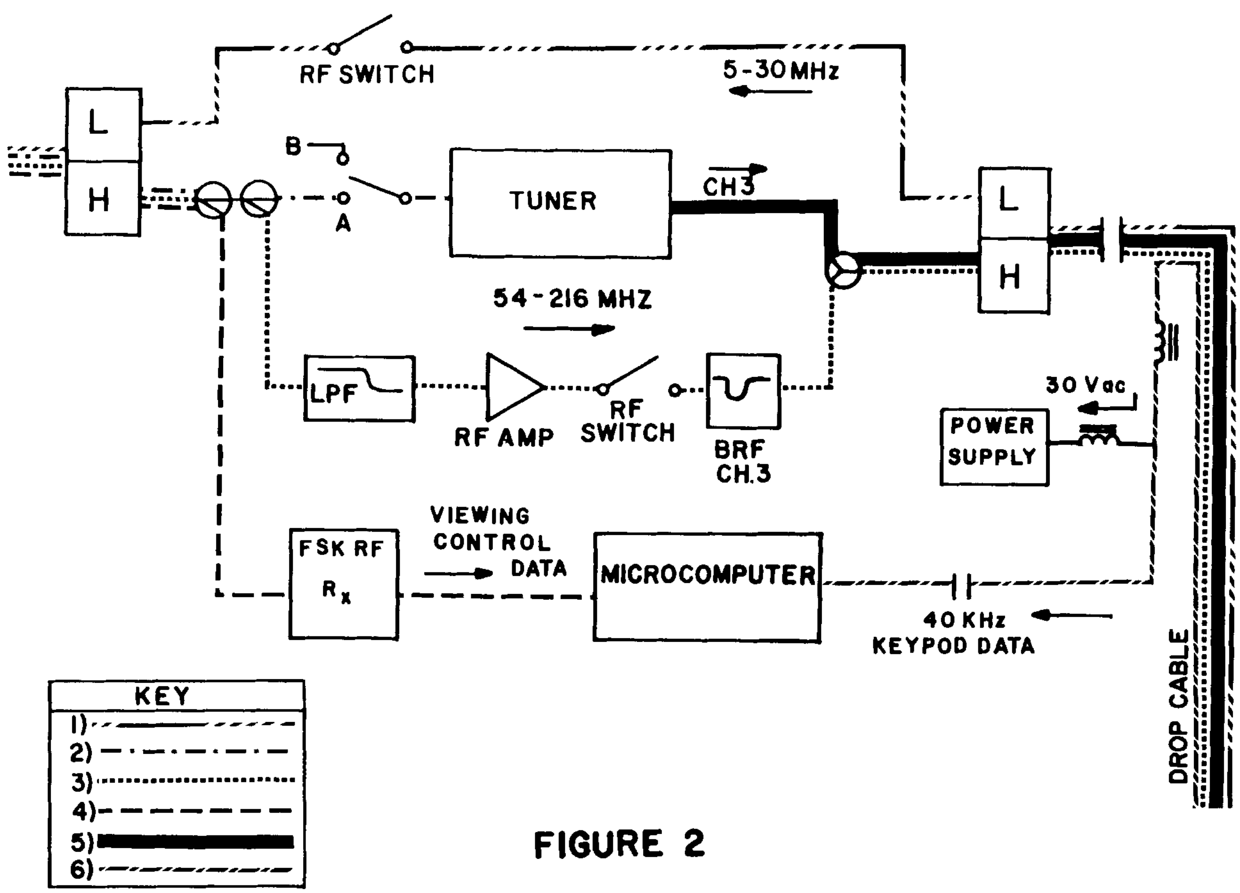


FIGURE 2

ditional path allows FM and unconverted service delivery to additional TV sets. The use of a controlled return path allows delivery of two-way service and isolates drops of non-two-way customers. The only disadvantage of this configuration is that Channel 3 may not be carried on cable A. We believe off-premises addressable converter systems presently offer the best solution to many CATV problems.

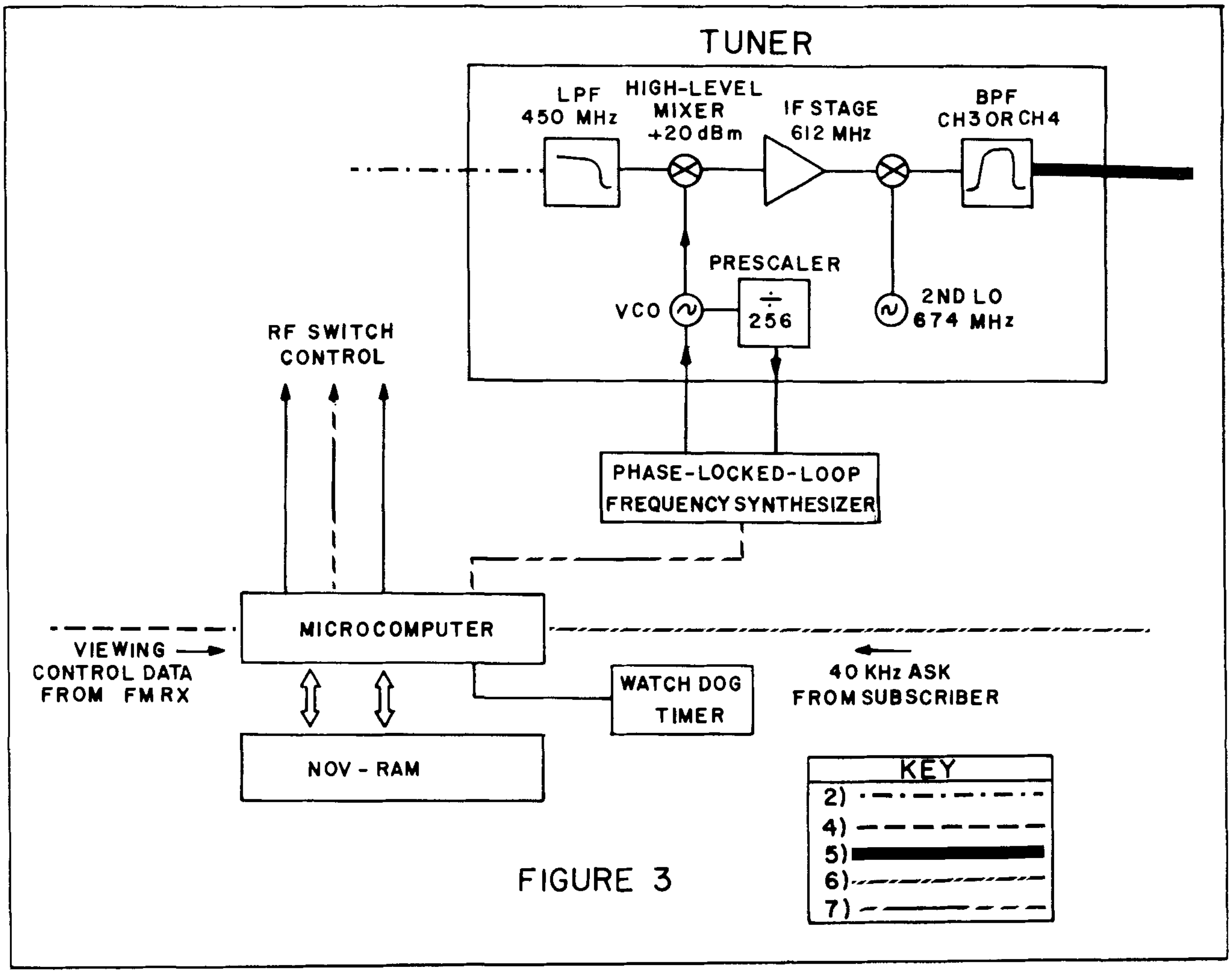


FIGURE 3

AUDIO NOISE REDUCTION IN CABLE SYSTEMS

S. Forshay, K. Gundry, D. Robinson, C. Todd

Dolby Laboratories Inc.

ABSTRACT: PART A

A newly developed compandor provides 23 dB of CCIR weighted noise reduction in a transmission medium where starting signal-to-noise ratio is on the order of 45 dB. A two-band approach consisting of the cascade combination of sliding and fixed band compandors provides a cost effective means of maintaining excellent audio quality in stereophonic television transmission. The compandor is discussed in terms of dynamic properties including overshoot performance, sensitivity to time dispersive transmission media, and reduction of correlated noise spectra common in intercarrier television design.

ABSTRACT: PART B

The delivery to the home of program audio in digital form would have many advantages, among them the potential for very high quality and ease of encryption. Conventional high quality digital-audio conversion schemes yield high bit rates at high cost. A conversion scheme will be described which yields high quality sound, modest bit rate, low cost, and inherent resistance to bit errors.

PART A: A HIGH THRESHOLD COMPANDOR FOR MULTICHANNEL TELEVISION SOUND

INTRODUCTION

The advent of multichannel television sound brings with it increased demand for quality in all associated transmission equipment, as well as some specific requirements for audio noise reduction. Addition of a difference channel component and a second language subcarrier to the baseband mono carrier represent a significant compromise in audio quality. This paper is intended to illustrate a cost effective approach providing stereo signal-to-noise performance equivalent to present monophonic transmission.

Existence of three proposals for a transmission system standard made it clear that any compandor developed would have to be designed to handle both de-emphasized white noise, characteristic of an FM-AM system, and de-emphasized triangular noise, characteristic of an FM-FM system. There are also varying degrees of correlated noise spectra such as intercarrier buzz, incidental phase moduation, and impulse noise. Typical modulation levels and bandwidth restrictions for the (L-R) subcarrier and second audio program channel indicate fringe area signal-to-noise ratios as much as 25 dB poorer than mono. Cable systems generally reduce aural carrier power 5 dB with respect to broadcast standards; a reduction in adjacent channel video interference acheived at the expense of audio noise performance. These considerations contributed to the choice of 40 dB as representative of worst case signal-to-noise conditions.

One of the prime requirements during early listening tests was "compatibility". Thinking at that time included processing of both (L+R) and (L-R) signals and required the compressed signal be listenable on monophonic receivers without expanders. B-type noise reduction (1), (2), (3) was suggested as a solution because of the gentle compression slope and modest amount of noise reduction. Unfortunately, those very desirable B-type characteristics limit the effectiveness of the compandor under the present conditions. B-type was designed to reduce noise characteristic of low speed consumer tape processes (predominantly high frequency in nature), and in doing so left a substantial amount of middle frequency noise apparent. The results clearly indicated a need for increased noise reduction effect which extended lower in the middle frequency range.

All noise reduction proponents were in agreement that the issue of compatibility was in conflict with providing the necessary noise reduction. A decision was made to allow compatible processing of the (L+R) signal if a proponent so desired, but to drop the compatibility requirement for (L-R) processing. The proponents were now free to apply more aggressive compandor algorithms and it was at this time that C-type noise reduction (4) was proposed for processing the subcarrier signal.

C-type provides 20 dB of CCIR-weighted noise reduction using two series-connected "sliding band" processors with separated areas of dynamic action. The processors operate at different thresholds to minimize peak compression ratios and undesirable side effects in channels with time variant frequency and phase characteristics.

Listening tests revealed improved middle frequency noise reduction, but not without audible noise modulation artifacts. The channel noise level limited overall noise reduction effect to 15 dB and caused the expander to mistrack. C-type was originally designed for consumer tape systems and was not intended to provide substantial low frequency noise reduction. Therefore, it was not surprising to note the presence of low frequency components of buzz after noise reduction. A new combination approach was needed maintaining the attributes of a high frequency sliding band device, while providing additional low frequency noise reduction to deal with buzz. A vote amongst the compandor proponents resulted in a majority decision to eliminate (L+R) processing due to the fact that (L-R) noise would ultimately limit stereo signal-to-noise performance.

THE COMPANDOR SYSTEM

The new circuit consists of two series-connected compandors operating in separated frequency ranges with differing amounts of noise reduction. The combined output provides increased noise reduction effect in the cross-over region with a modest increase in maximum compression ratio. A block diagram of the compressor is shown in figure 1, with the corresponding expander shown in figure 2. The well documented "dual-path" approach is used in which a dynamically modified signal in the "side-chain" is summed with a dynamically unmodified signal in the "main path". A compressor is formed via in-phase summation, while the complementary expander function is derived via negative feedback.

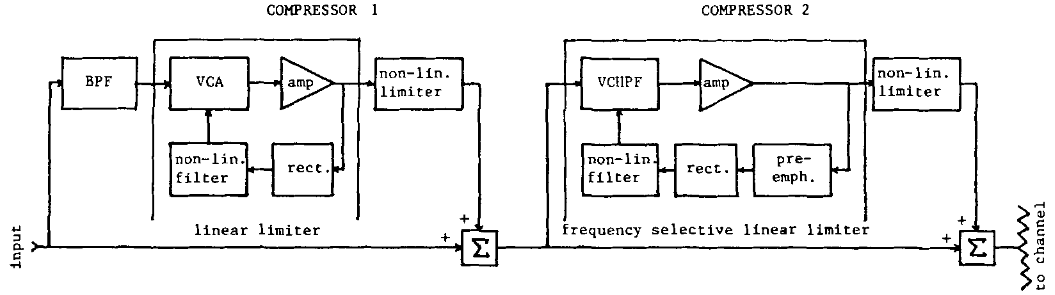


Fig. 1. Compressor block diagram.

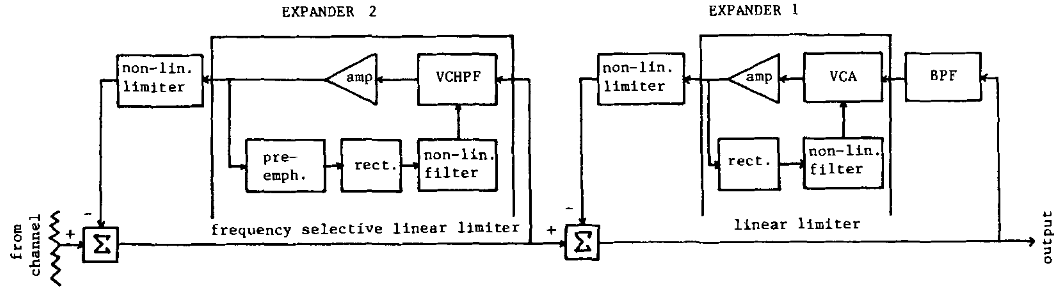


Fig. 2. Expander block diagram.

Compressor 1 is a fixed band device similar to one band of A-type (5) formed by bandpass filtering the input to a voltage controlled attenuator (VCA), in a one-decade range beginning at 80 Hz. An amplifier following the VCA provides the means of adjusting the maximum contribution of the side-chain signal to the compressor output. Attenuation of the VCA is a linear function of control signal which is a full-wave rectified representation of the side-chain output, smoothed by a non-linear filter. Compressor 2 is a sliding band device formed by passing the input signal through a voltage controlled high-pass filter (VCHPF), where the cutoff frequency is threshold-limited to a minimum of 2.2 kHz. An amplifier following the filter again provides a means of adjusting the maximum contribution of the high frequency side-chain to the compressor 2 output. The VCHPF cutoff frequency is a linear function of control signal which is a pre-emphasized, full-wave rectified representation of the high frequency side-chain output, smoothed by a second non-linear filter.

Dynamic Properties

The "bi-linear" nature of the transfer characteristic is illustrated in figure 3. At levels below threshold, side-chain signal dominates the compressor output. As input level increases, the side-chain (a combination of linear and non-linear limiters), contribution becomes less significant and the transfer function approaches unity gain. This configuration provides a effective means of controlling compressor overshoot. Overshoot is the result of time delay in the control path and is equal in amplitude to the change in compressor gain during the transient interval (and thus statistically dependent on source material). Overshoot duration can be minimized by decreasing compressor attack time, but only at the expense of increased susceptibility to expander mistracking (i.e. a compressor with a very fast attack generates additional high frequency components which may extend beyond the channel bandwidth; if these spectral components are attenuated or subjected to phase aberrations, expander mistracking will result).

A non-linear limiter (symmetrical clipper), operates on the side-chain output signal clipping off high level overshoots. The side-chain contribution is reduced at high levels and the resulting distortion (several percent), is short enough in duration (about 1 msec), to be effectively masked by the unaltered signal component of the main path. An identical clipper is used in the expander where complementary subtraction of the distortion products occurs. The relatively small overshoot component at the compressor output (typically 2 dB with average program material), can be handled without significant compromise in the use of channel dynamic range. This also allows the compandor to achieve the full noise reduction effect.

In theory, for transmission paths time dispersive in nature, it is desirable to use rms detection in generation of the compandor control signal. This requires the integration time be long compared to the period of the signal; a direct conflict with good transient performance. In practice, a simple non-linear filter network which combines signal averaging and peak detection provides a sufficiently close approximation without the cost and complexity of rms detection (4).

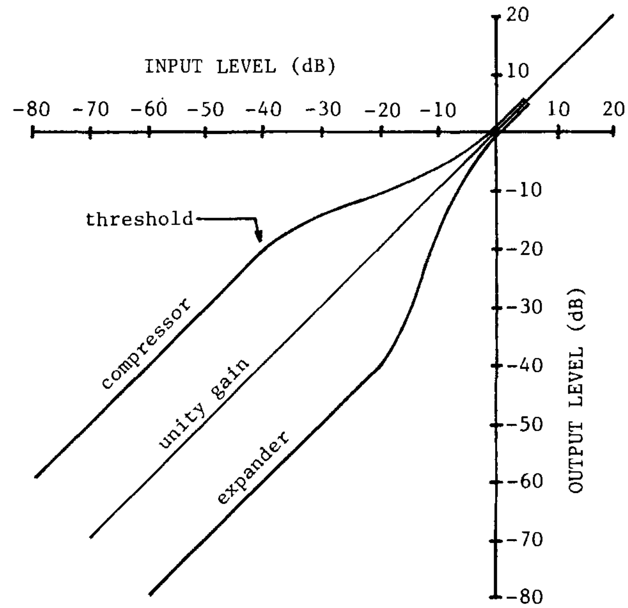


Fig. 3. Input-output characteristics (at 2KHz).

The compandor non-linear filter configurations are identical with time constants optimized for each band of operation. Attack time varies with the dynamic nature of the input signal and is relatively long for transients of moderate level. The resulting overshoots are linearly handled in the transmission path. Large transients cause the filter time constant to adapt to a minimum fixed value shortening the overshoot interval in such a way that modulation products (sidebands), will be masked by the transient itself. The compressor can be modeled as an amplitude modulator which trades dynamic range for signal bandwidth thru multiplication of source and control signal. Attack time must be sufficiently long to maintain psychoacoustic masking of multiplier sidebands and prevent generation of modulation products which extend beyond channel band-limiting filters (attenuation and filter time dispersion cause the expander to generate transient distortion). Compandor release time is critical as well. Designs with single pole control path filters generally require trade-off between response time and distortion caused by ripple. However, the non-linear filter consists of a two pole circuit which reduces ripple distortion and noise modulation products (noise tails due to lengthy release time). A second factor considered in the choice of release time is a psychoacoustic effect whereby sensitivity of the ear is reduced immediately following a transient (5). A release time on the order of 50 msec provides very satisfactory subjective performance.

Band Splitting

Elementary compandors such as those used in telephony are broadband devices consisting of a single signal path. Devices of this nature are best suited for use over narrow portions of the audio spectrum such that the probability of generation of noise modulation artifacts and modulation products is reduced. Wideband compandors exhibit excellent noise reduction properties in the absence of signal, but due to the broadband nature of the detector, the presence of moderate to high level low frequency signals will reduce dynamic action and high frequency noise will become audible (the reverse is also true). Signal pre-emphasis is often used in an attempt to minimize these effects. In contrast, the sliding band (VCHPF) is optimized to take advantage of a second psycho-acoustic phenomena whereby noise in the immediate band surrounding a high level signal is masked in the presence of such a signal, thereby reducing the requirement for noise reduction in that band (5). A signal with dominant mid-frequency energy (f1), will cause the VCHPF cutoff frequency to increase, reducing dynamic action in the region of the signal (where noise is effectively masked), while maintaining noise reduction at higher frequencies (see curve 1 figure 4). A signal in the region of f2 will increase the VCHPF cutoff frequency proportionally more for a given energy level; illustrating the signal adapting nature of the sliding band (see curve 2 figure 4). High frequency noise modulation by low frequency signals is also reduced due to the variable selectivity of the VCHPF. Sliding band technique can be adapted for use at low frequencies but the cost and complexity are not justified in this application. Therefore, a narrow fixed band compandor is cascade connected to provide low frequency noise reduction. The operating bandwidth of the low frequency band is optimized to provide 14 dB of noise reduction with minimal out-of-band modulation effects. Curves illustrating individual and combined compressor contributions (for levels below threshold), are shown in figure 5. First order filter slopes are required in order that summation of the compressor responses result in the smooth overall characteristic shown. The summation process also provides additional middle frequency noise reduction with only a modest increase in peak compression ratio.

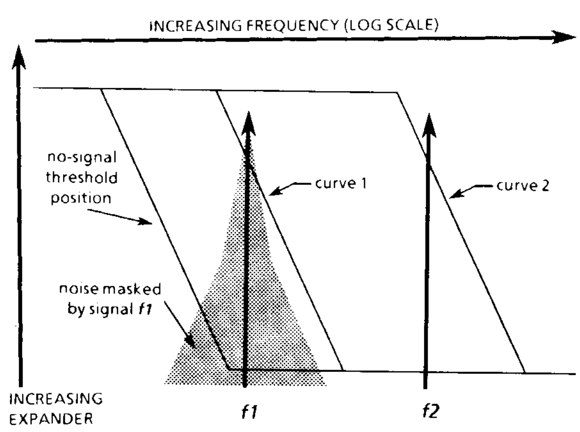


Fig. 4. Signal adapting nature of the sliding band processor.

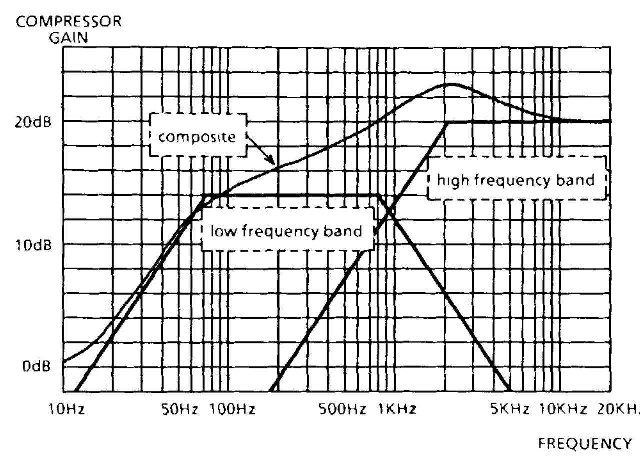


Fig. 5. Compressor gain vs. frequency (below threshold).

SUMMARY

A new companding configuration has been described which provides superior broadband noise reduction characteristics in the presence of high channel noise. This high threshold device functions so as to maintain monophonic audio quality for stereo transmission at the Grade-B service contour limit. In addition, the compandor is ideally suited for use in transmission paths where frequency response characteristics are well defined, and signal-to-noise ratio is as low as 40 dB. Listening tests conducted using very critical program sources including isolated bells, wood blocks and additional highly transient material have shown the compandor to be relatively free of noise modulation artifacts commonly associated with wideband high compression devices.

REFERENCES

(1) R. M. Dolby, "A Noise Reduction System for Consumer Applications", presented at the 39th Convention of The Audio Engineering Society, New York, (Oct. 1970).

(2) D. P. Robinson, "Dolby B-type Noise Reduction for FM Broadcasts", J. Audio Eng. Soc., vol. 21, pp. 351-356 (June 1973).

(3) R. M. Dolby, "Optimum Use of Noise Reduction in FM Broadcasting", J. Audio Eng. Soc., vol. 21, pp. 357-362 (June 1973).

(4) R. M. Dolby, "A 20 dB Audio Noise Reduction System for Consumer Applications", presented at the 70th Convention of the Audio Engineering Society, New York, (Oct. 1981).

(5) R. M. Dolby, "An Audio Noise Reduction System", J. Audio Eng. Soc., vol. 15, p.383 (Oct. 1967).

PART B: AN ECONOMICAL HIGH PERFORMANCE DIGITAL CODING SCHEME

INTRODUCTION

A good number of analog to digital coding schemes exist, the most common being linear PCM. With adequate sampling rate and number of quantization levels very high quality is obtained. This has become the system of choice for both professional and for highest quality consumer use. However there are many applications where the complexity, performance, and expense of PCM are inappropriate. For several of these applications, the form of encoding known as Adaptive Delta Modulation (ADM) has significant merit. Properly applied, analog noise reduction techniques overcome the inherent performance limitations of this inherently simple and low cost technique.

PCM

The theory of PCM is straightforward and well established. If we sample at more than twice the highest audio frequency, the signal-to-noise ratio of a linear PCM system can be expressed as $\sqrt{1.5} \times 2^n$, where n is the number of bits per sample. Examples of typical systems are the digital compact disc which quantizes to 16 bits at 44.1 kHz and the EIAJ format for recording PCM on video cassettes which employs 14 bit quantization at 44.1 kHz. These systems have bit rates of about 700 kb/s and 600 kb/s, and costs associated with conversion to accuracies better than .006% and .0015%.

In order to reduce both cost and bit-rates, companding techniques have been often been applied.

a) Analog companding. Inadequate PCM systems (e.g., 10 bit) can be combined with analog companders. If the noise reduction system is well designed, this approach can work satisfactorily.

b) Instantaneous digital companding. If the analog signal has been quantized to a high precision (14-16 bits), the transmitted bit-rate can be reduced by sending the samples with full resolution only when they are small in magnitude (low level signals). Larger samples are sent with coarser resolution, and quantizing error is therefore increased.

c) Block digital companding. This is similar to b) above, but the reduction in resolution occurs over blocks of data (e.g., 16 or 32 samples) in accordance with the magnitude of the biggest sample within each block. This method gives a greater saving in bit-rate.

Digital companders resemble analog wideband companders in that the level of the quantizing error rises as the signal level rises, and the spectrum of the quantizing error is independent of the nature of the signal; that is, digital companders are fundamentally susceptible to audible noise modulation. Since the spectrum of the quantizing error from a PCM system resembles white noise, which to the human ear is predominantly high frequency, noise modulation is most likely to be audible in the presence of low frequency signals. Our experiments have shown that if the noise above 2 kHz rises to worse than 65 to 70 dB below full-scale in the presence of say a 200 Hz full-scale signal, then noise modulation will be audible on critical musical material. With moderate amounts of pre- and de-emphasis this requirement can be met if the minimum resolution in the presence of full-scale signals corresponds to a 10 bit system.

The British Broadcasting Corporation's NICAM 3, a block range-switching scheme with initial quantization to 14 bits, digitally companded to 10 bits with pre-emphasis, is an example of an optimized system. Digitally companded systems whose resolution drops below 10 bits can be expected to give audible noise modulation under critical conditions.

Digital companding schemes are unattractive for consumer applications because they retain the cost disadvantages of linear PCM, resulting from the need for 14 or 16 bit converters, and the required bit rates remain moderately high (a minimum of about 320 kbits/s per audio channel if noise modulation is to be avoided).

DELTA MODULATION

Delta modulation (DM) can be considered as a special case of differential PCM in which only one bit quantization is performed at a high clock rate. DM is a signal following system. The DM decoder steps up or down with each incoming bit. An encoder is made from a decoder with the addition of a comparator. Figure 1 shows a simple encoder and decoder. The theoretical SNR of a simple DM system is

$$N \geq \frac{\sqrt{3}}{4\pi} \cdot \frac{F^{3/2}}{f_m f_s^{1/2}}$$

where fm is the frequency of a sine-wave at full scale, fs is the audio bandwidth, and F is the sampling frequency. The equality applies when there is no correlation between successive samples; in practice the sampling frequency F is normally much greater than 2fs, so that there is always a high degree of correlation. The resulting value of N is typically 2-3 dB better than that calculated from this formula.

The full scale signal level of a DM system falls at 6 dB/octave with increasing signal frequency; the system is slope limited. A DM system operating at a bit rate on the order of 200-500 kbits/s will have a SNR considerably inferior to a PCM system operating at the same bit rate. Figure 2 shows the quantizing error of a DM system relative to the level of a full-scale signal as a function of the signal frequency with a sampling frequency (and thus bit rate) of 250 kHz. The dotted line shows the equivalent information for a PCM system at a similar bit rate (8 bit, 32 kHz).

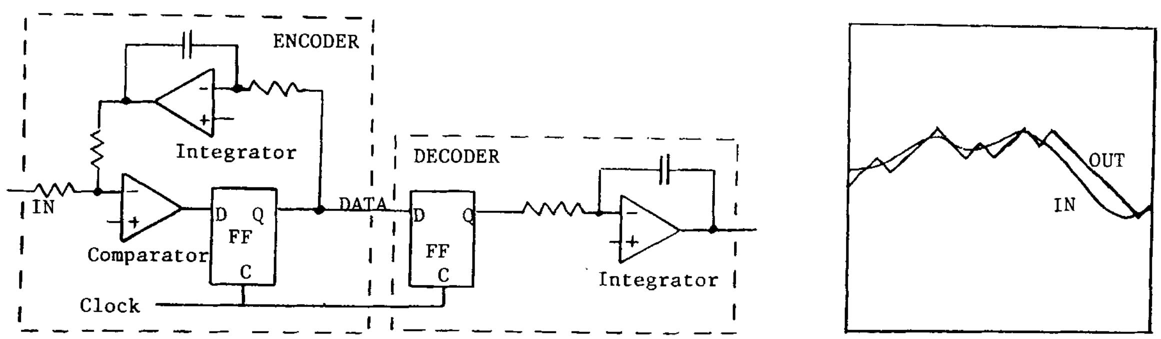


Figure 1: Basic Delta Modulation System

ERROR FEEDBACK

A well known flaw of DM is that the quantizing error resulting from sine-wave inputs does not resemble random white noise, but contains discrete frequencies, or birdies. Error feedback is a technique where the output of an imperfect transmission path is compared with its input and the discrepancy due to the imperfection is added to the input signal in such a sense as to reduce the discrepancy. Since DM is a grossly oversampled system much of the quantizing error lies above audio frequencies. The application of error feedback in the audio band reduces the quantizing error (including the birdies) at audio frequencies at the expense of increased error at frequencies above audio where it is of no significance. In practice, birdies are reduced to inaudibility and audio band noise is reduced by about 10 dB as shown in Fig. 2.

COMPANDED DM

The dynamic range of DM can be improved by the application of companding techniques. An ideal compander would adjust system gain so that the signal is always converted at full scale, whatever its amplitude or frequency content. This objective cannot be achieved by an analog compression-expansion system controlled by the analog signal itself, since it implies an infinite compression ratio, and therefore an infinite expansion ratio (requiring infinite precision for proper tracking). A digital (or quantized) compander in which the step-size adopts one of a discrete number of values, can provide an approximation to the ideal characteristic. Unfortunately this requires very high precision, comparable with PCM system, because errors in step-size lead to discontinuities in the slope of the reproduced audio, and hence additional error.

However, by using a hybrid analog-digital approach, an almost ideal characteristic is achieved. The step-size is made continuously variable at a syllabic rate under the control of the bit-stream. When the data contains long strings of 1's or 0's, indicating that the coder is lagging behind the input signal, the circuit tends to increase the step-size until the strings are broken up. The step-size varies in accordance with the short term peak value of the slope, adapting so that the modulator is always close to full-scale. High precision is not required as discrepancies between the encoder and decoder lead to a small low frequency amplitude modulation of the signal. An unusual property of Adapting Delta Modulation (ADM) is that there is no inherent maximum or minimum of the control signal level, so in theory the dynamic range is infinite. In practical circuits limitations are introduced by amplifier noise sources and power supply rails.

PROGRAM-ADAPTING PRE-EMPHASIS

The subjective performance of ADM with error feedback can be enhanced by a program-adapting response shaping system. Consider the following signal conditions:

a) When signal amplitudes are small, high frequency emphasis in the coder and de-emphasis in the decoder can improve the subjective noise level by reducing the noise power in the part of the spectrum where the human ear is most sensitive.

b) When the input signal contains large amplitudes at low frequencies alone, a degree of low frequency attenuation in the coder, and corresponding boost in the decoder reduces the extent of step-size adaptation and therefore reduces the change in high frequency noise due to the increases in step-size.

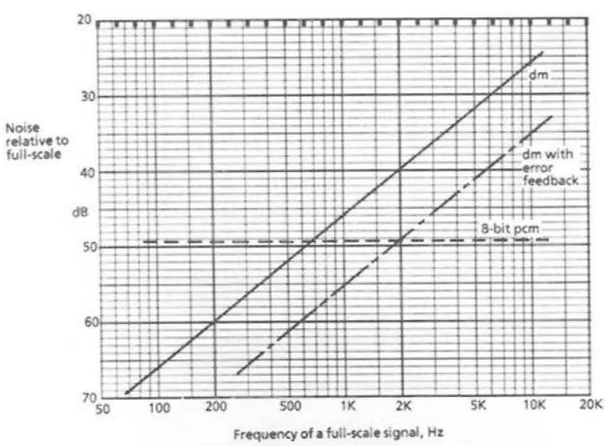


Figure 2: Ratio of maximum signal to noise as function of frequency of a full-scale (sine-wave) signal.

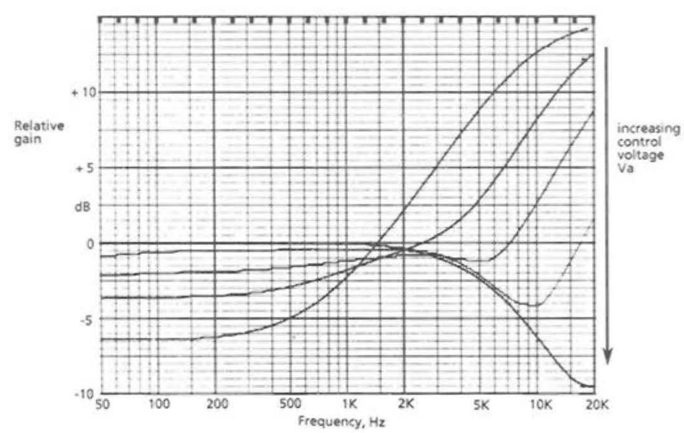


Figure 3: Typical set of responses of adaptive pre-emphasis
(measured results)

c) When the signal contains high amplitudes at high frequencies, the effect of both the high frequency emphasis and low frequency attenuation in the coder is to boost the low frequency noise in the reproduced signal; it is therefore desirable to reduce these response changes, or even to invert their directions.

Hence a family of emphasis characteristics of the form shown in figure 3 give good results. Since the significant factor in determining the required characteristics is the slope of the input signal, which in turn is directly proportional to the step-size, it is possible to control the emphasis with the same information (derived from the bit-stream) that controls the step-size.

As with any signal-controlled syllabic compander, the adapting pre-emphasis of ADM might be expected to display a lag between the onset of a large amplitude signal and the adaptation of the circuit, with a resultant need to compromise between speed of response and modulation distortion. In the adaptive pre-emphasis this compromise is greatly reduced by using a two-path configuration, in which the pre-emphasized components of the signal present in both encoder and decoder are subjected to non-linear complementary overshoot suppression, similar to that used in the Dolby analog noise reduction systems.

PRACTICAL IMPLEMENTATION

Figure 4 shows the block diagram of a practical encoder. The decoder would use the same functional blocks except that the comparator (10) and the error feedback (8 and 9) blocks are not required. This system has been built using standard off-the-shelf op-amps and CMOS logic. For mass production a large scale I.C. is envisioned. A feasibility study conducted for us by Silicon Systems Inc., the California IC company known for its expertise in switched capacitor techniques, has concluded that the whole converter can be condensed to one chip with an area of $20mm^2$, requiring only a few non-critical external capacitors and a source of clock. The I.C. would be capable of switching between encode and decode modes.

PERFORMANCE

The frequency response of the system is determined almost entirely by the input and output filters, which can be simple two- or three-pole low pass filters. Assuming a sampling frequency of 250 kHz, a response up to 16 kHz (or even 20 kHz) can be achieved.

The overload point of the system is determined by the supply rails. The noise level is proportional to the level of the control signal, which in principle can decay to zero yielding an infinite dynamic range. Practical

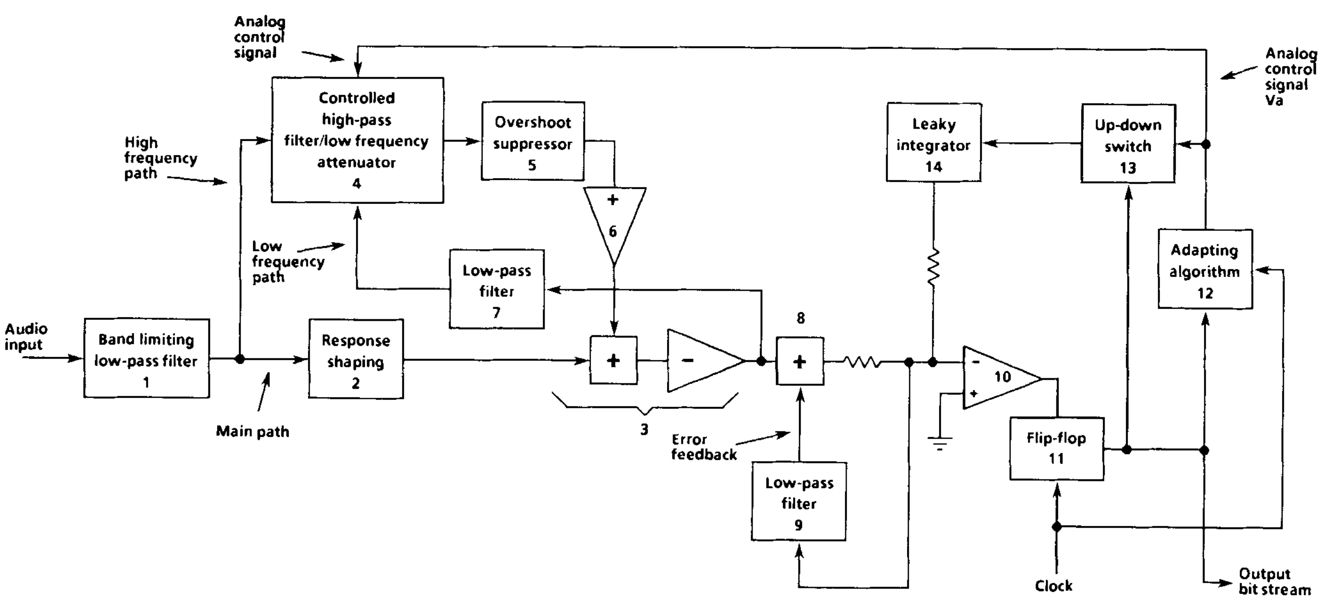


Figure 4: __Practical Encoder__

circuits of course contain noise sources so the control signal will remain large enough to encode the encoder's own noise sources into the bit stream. The combination of the encoder and decoder amplifier noise sources limit the dynamic range. Using typical I.C. op-amps the dynamic range is on the order of 100 dB.

Since the noise is a function of the signal (as with any companded system, analog or digital), the signal-to-noise ratio is not the same as the dynamic range. Realistic assessment of noise in the presence of signals requires consideration of masking. We have made measurements of high frequency noise in the presence of low frequency signals, and low frequency noise in the presence of high frequency signals. Figures 5 and 6 give examples of these measurements, together with the limits of audiblity. It is apparent that the noise modulation is unlikely to be audible on critical material. For perspective, calculated points for the NICAM 3 system are indicated.

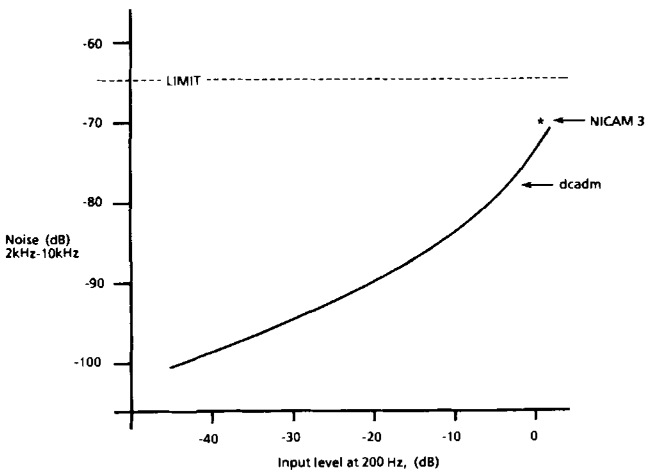


Figure 5: High frequency noise v level of low frequency signal
(measured results, 0dB = full-scale)

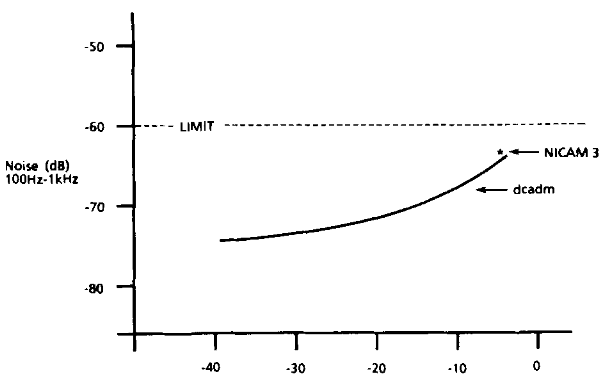


Figure 6: Low frequency noise v level of high frequency signal
(measured results, 0dB = full-scale)

Figure 7 shows the dynamic performance of the system. The test signal is a high frequency transient. The overshoot suppression eliminates the normal transient distortion resulting from the finite response time of a syllabically adapting system; the rounding at the beginning of the tone burst is largely the result of the low pass filters.

DIGITAL DATA ERRORS

The reason for converting audio signals from an analog into a digital representation is to assure more reliable transmission of the signals, since digits may be transmitted with essentially no error. Error free transmission has a price however, in that excessive amounts of bandwidth or power may be required. Since a practical system should be designed for efficient use of the channel, there will typically be some finite error rate.

Digital errors may be dealt with in several ways. If the error rate is low enough, the errors may simply be ignored, and the resulting sound quality degradation tolerated. One method to deal with the errors is to detect which bits are in error by means of a parity or algebraic check code. The unreliable bits can then be detected and discarded (turning the bad data into erasures instead of errors) and some type of error concealment can be employed in the DAC. The ideal method of handling errors is to transmit extra redundant bits along with the audio bits so that errors may be detected and actually corrected in the digital domain. However, an Error Detection And Correction (EDAC) system entails considerable complexity, and will itself fail when the raw error rate is sufficiently high, thus requiring error concealment in the DAC. In the design of a digital transmission system the effect of digital errors on audio quality should be considered. The nature of the degradation of various types of A-D-A conversion systems when subjected to digital errors can have a significant impact on overall system design.

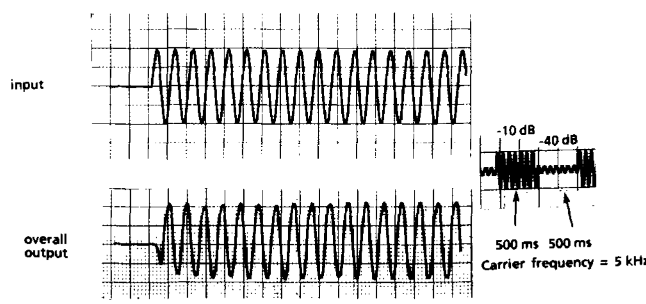


Figure 7: Typical response to a high level transient

The effect of digital data errors or erasures on PCM systems is well known. An isolated one bit error can result in an impulse of amplitude ranging from negligible (for an LSB error) to half of full scale (for an MSB error) as shown in figure 8. Even a low error rate can obviously have a severe impact on a PCM system. Isolated erasures, however, can be handled quite comfortably by a PCM system since straight forward linear interpolation can replace an erased value. Provided these erasures do not occur too frequently, the effect of this error concealment is quite innocuous. Linear interpolation can only conceal isolated erasures and not burst erasures; if burst erasures are likely to occur, interleaving is usually employed so that a burst error is transformed into a repetitive error.

The effects of digital errors or erasures on an ADM system are quite different from a PCM system. An isolated one bit error will cause the decoder to integrate in the wrong direction for one clock cycle, as shown in figure 9. This has the effect of adding a small step to the audio waveform. The amplitude of this step is never large because every bit has equal weight--one quantum of resolution. Additionally, the spectrum of this disturbance is subjectively less annoying than that with PCM since it is shifted towards lower audio frequencies.

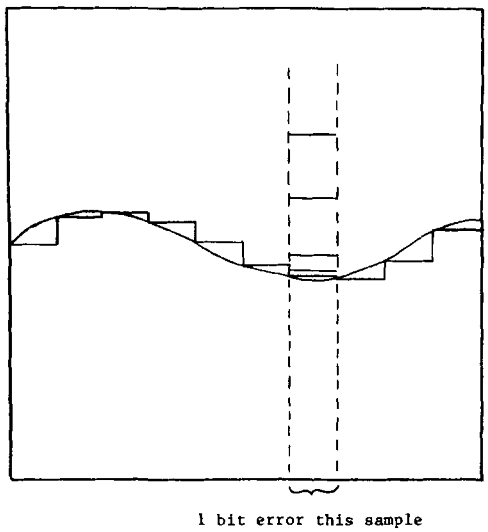


Figure 8a: Effect of a one bit error in a PCM system

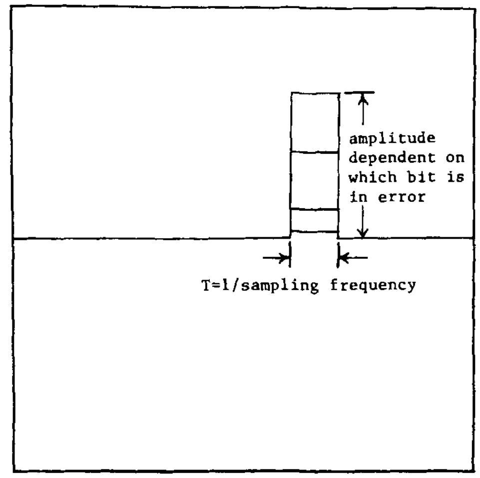


Figure 8b: Error generated by a one bit PCM error

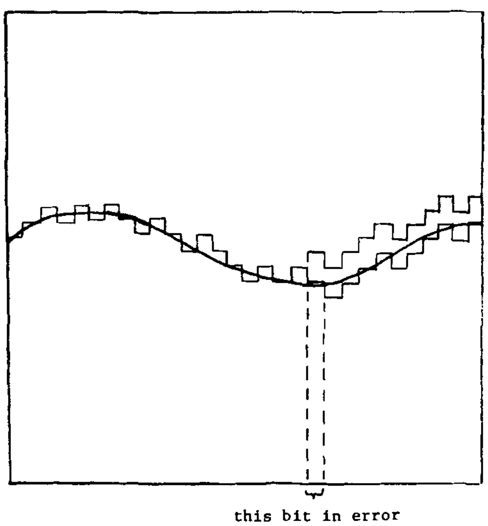


Figure 9a: Effect of a one bit error in a DM system

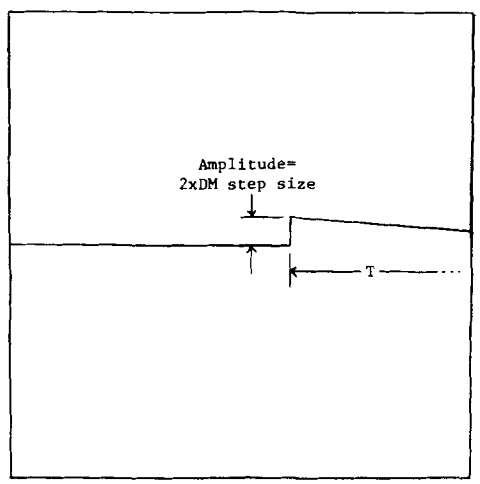


Figure 9b: Error generated by a one bit DM error
(The error decays at a rate set by the integrator leak)

The innocuous effect on reproduced audio of an ADM bit error can yield some very great system advantages. Consider a digital transmission system with a bit error rate of 1E-5. This would lead to very audible impulses occurring a couple of times per second with PCM coding, but would be barely audible with ADM. The PCM would require some form of error control in the transmission system; the ADM would not.

APPLICATIONS

The performance of a digitally controlled ADM system with program-adapting pre-emphasis as described are similar to those of an optimally designed digitally companded PCM system such as NICAM 3. However the ADM operates at a somewhat lower bit-rate (250 kbits/s vs. 322) and eliminates the need for the expensive 14-bit converters and high-order anti-aliasing filters. The ADM tolerance for errors means a perfect transmission channel is not required. ADM is therefore very attractive for consumer applications, including direct distribution of program to the home via cable.

ACKNOWLEDGEMENTS

We would like to acknowledge the contributions of Richard DeFreitas of Delta Lab Research who showed that ADM was a suitable technique for high quality audio, and G. Jacobs and M. Smith at Dolby Laboratories.

REFERENCES

(6) C.R. Caine, A.R. English, J.W.H. O'Clarey, "NICAM 3: near-instantaneous companded digital transmission for high-quality sound programmes", Radio and Electronic Engineer vol. 50 No. 10, pp. 519-530, Oct. 1980.

(7) H.R. Schindler, "Delta modulation", IEEE Spectrum, vol. 7, pp 69-79 (Oct. 1970).

(8) C.C. Cutler, "Transmission systems employing quantization", U.S. Patent No. 2927962 (1960).

(9) H.A. Spang, P.M. Schultheiss, "Reduction of quantizing noise by use of feedback", IRE Trans. Commun. Syst. vol. CS10 pp. 373-380 (Dec. 1962).

(10) R.E. DeFreitas "Digital encoding circuitry with means to reduce quantization noise" U.S. Patent No. 4313204 (1982).

(11) K. Gundry, D. Robinson, C. Todd "Recent Developments in Digital Audio Techniques", AES Preprint No. 1956, March 1983.

Cable Signal Leakage: Where is it all going?

John P. Wong

Cable Television Branch, MMB
Federal Communications Commission

ABSTRACT

Peaceful co-existance, that's the key! It has been more than a dozen years ago since cable television operators, in search of additional channel space, expanded into the frequency spectrum between television channels 6 and 7 (midband). During the same time period the Federal Aviation Administration (FAA) expressed concern about the potential problems associated with cable's usage of the midband and superband (specifically the frequency bands between 108 - 136 MHz and 225 - 400 MHz). The cable industry's battle cries of: cable is a closed system, cable doesnot make airplanes fall out of the sky, and the FAA should police its own before coming down upon innocent cable operators, have all been heard. The pros and cons of the issue have been considered, but still there has yet to be found an acceptable solution to the problem.

By delving into the past, and looking at the present, the author will suggest a compromise solution for this troublesome problem that is going well into its second decade.

INTRODUCTION

Cable Signal Leakage: Where has it been?, Where is it going?

Answering the above questions tactfully while maintaining a regulatory stance has not been easy for the Federal Communications Communication (FCC). Nonetheless, because of the potential "safety of life" question associated with the cable signal leakage issue, the FCC must confront the issue and establish a workable regulatory policy.

Since the early 1970's, the FCC, the FAA, the National Telecommunications Information Agency(NTIA) and the Cable Television Industry, independently and collectively, strived to work toward a viable solution to the cable signal leakage dilemma. The results of the various experiments performed appeared to produce a satisfactory middle ground. However, at the most inopportune times, cable signal leakage related interferences would occur. Inevitably, these incidents would raise new questions which would result in a revisit of the compromise.

The last round of exchanges between the cable operators and the government regulators had been fierce with both sides determined to stand their grounds. The battle may be short lived, because despite the opposition, the Commission is compelled to rely upon the past performances of the cable operators to set the appropriate regulation on this sensitive issue.

WHERE HAS IT BEEN?

The following is a summary of the history of events on cable signal leakage.

1971 - The FAA became concerned with cable's use of aeronautical navigations and aeronautcal communications frequencies.

1972 - The Office of Telecommunications Policy (OTP) of the Department of Commerce expressed their concern to the FCC. The OTP proposed usage restrictions on cable operators and at the same time commissioned the Institute of Telecommunications Studies (ITS), now National Telecommunications and Information Administration (NTIA), to investigate the concern.

- In the same year, the FCC initiated rulemaking (36 FCC 2d, 143 (1972)) sans specific restrictions on cable operators. The FCC cited the lack of an actual interference report and the minimal interference probability as its reasons for not imposing restrictions.

1974 - The ITS issued its report demonstrating that various combination of events may result in interference to aeronautical radio users.

1975 - The FCC issued a public notice indicating cable's potential for interference to aeronautical usage.

1976 - First documented case of interference to to aircraft frequencies discovered over Harrisburg, Pa. The cable operator was using the same frequency as the affected aeronautical channel and the cable system was not in compliance with the then existing FCC radiation limits.

- The OTP requested immediate action by the FCC to eliminate future occurrances.
- The FCC released the first Notice of Proposed Rulemaking (NPRM), Docket 21006, (61 FCC 2d 1022 (1976)), on cable signal leakage interference prevention.

1977 - The OTP responded to the FCC on the NPRM. In its comments, the OTP didnot request the cable operators to vacate the aeronautical radio bands while studies of the problem is underway.

- In its comments, the FAA requested the ban of all cable operations in the aeronautical bands until adequate rules were developed and more importantly, were enforceable.
- The FCC adopted the interim rules (47 CFR 76.610 -76.613). The rules did not ban cable usage within the aeronautical bands but did required distance separation and frequency offset by cable operators in those bands.

1978 - The interim rules became effective.

- The Advisory Committee on Cable Signal Leakage were formed to investigate the issue. The committee comprised of the FCC, FAA, NTIA, cable industry representatives and private aviation interest groups.
- Second documented case of interference from cable leakage occurred over Hagerstown, Md. It was an on-frequency interference to an identification channel of a VHF Omni-Range (VOR). The cable system was in violation of the interim rules and didnot meet the FCC's radiation limits.
- Third documented case interference to a low altitude en route communications channel over the vicinity of Oxnard and Ventura, Ca. There was no frequency separation between the cable frequency and the air-communications channel. The cable operator was again in violation of the interim rules and the established radiation limits.

1979 - Fourth documented case of interference occurred over Wilmington, NC to an approach control communications channel. This was also an on-frequency interference from the cable system. The system was in violation of the interim rules and exceeded the Commission's leakage standards.

- The Final Report of the Advisory Committee on Cable Signal Leakage was released.

1980

Mar - Based upon the conclusions of the advisory report, further NPRM (Docket 21006) was released by the FCC for comments.

Sep - The comments on Docket 21006 were completed.

Sep - Fifth documented case of aeronautical interference occurred in a high altitude (25,000-40,000 ft) en route sector within the vicinity of Flint, Mi. The cable frequency used was not offset from the air communications channel. Once again, the cable system was not in compliance with the FCC's Rules.

Dec - The FCC's Cable Television Bureau (CATV Bureau) enacted forfeiture procedures on signal leakage from cable systems.

1981

Feb - The FCC amended its interim rules to forbid cable usage of aeronautical frequencies without prior clearance by the Commission.

Feb - The CATV Bureau directed the FCC's Field Operations Bureau (FOB) to randomly inspect cable systems nationwide for compliance with the interim rules.

Feb - The CATV Bureau requested assistance from the Data Automation Division (DAD) of the Office of Managing Director and the Office of Science and Technology to formulate an aeronautical frequency notification processing system (AFP-CABAL).

Mar - The enforcement branch of the CATV Bureau directed numerous cable operators to vacate channels already in use within the aeronautical bands until compliance with the rules has been met.

Apr - FCC fined three cable systems a total of thirty seven thousand and five hundred dollars ($37,500) for violations to the interim rules and the radiation standards.

Aug - Initial AFP-CABAL system completed.

Nov - The FOB was directed to step-up the cable inspections program on aeronautical frequency usage.

Nov - The American Radio Relay League (ARRL) and numerous other amateur radio groups filed complaints of interference to their bands by cable operators to the FCC.

1982

Jan - A petition for rulemaking was filed by the ARRL. Within the petition, the ARRL request- the prohibition of cable operation on the Amateur Radio Service frequencies (HAM).

Mar - FCC released rulemaking RM-4040 in reply to the ARRL petition.

Mar - The draft action plan to automate AFP-CABAL approved.

Aug - The FAA requested the FCC for assistance to investigate the source of interference to an Instrument Landing Station (ILS) in Florida. The interference had rendered the ILS inoperable for approximately forty five (45) days. The interference was not pinpointed to cable signal leakage, but did mischievously disappear when the local FOB field office queried the surrounding cable systems on aeronautical frequency usage.

Oct - A cable system in California was fined for excessive leakage and interference to area HAMs.

Oct - Various cable systems in California was requested to vacate cable channel H in view of interference to a fire patrol frequency used by the Forestry Service.

Nov - CATV Bureau requested the FOB to perform Phase II inspections and continue enforcement of the cable signal leakage program.

1983

Jan - FCC wanted to go forward on Docket 21006 with changes.

Apr - AFP-CABAL system ready for testing and subsequent implementation.

WHERE IS IT NOW ?

FCC Rules

At the present time, cable operators have to abide by the following FCC Rules and Regulations.

Section 76.605(a)(12) (47 CFR 76.605(a)(12)) Technical Standards.

a) radiation limit of 20 microvolts per meter at ten feet for frequencies from 54 - 216 MHz.

b) for all other frequencies, the limit is 15 microvolts per meter at 100 feet.

Section 76.609 (47 CFR 76.609) Measurements

a) methods and procedures for radiation measurements.

Section 76.610 (47 CFR 76.610) Operation in the Frequency Bands 108 -136 MHz and 225 - 400 MHz.

a) applicable to all carriers and subcarriers with peak power levels of 10 microwatts (28.75 dBmV) or above on the cable distribution system.

1) cable operator must notify Commission annually of all frequencies carried.

2) clearance of frequencies must be obtained

prior to carriage on cable system.

3) Cable operator must monitor and maintain a leakage log encompassing the entire system once a year.

4) Cable systems within 60 nautical miles of aeronautical radio stations must have the following offsets:

   a. 100 kHz + tolerance (T) in the air communications bands (118-136 MHz, 225-328.6 MHz and 335.4-400 MHz).

   b. 50 kHz + T for the air navigational bands (108-118 MHz and 328.6-335.4 MHz).

5) If an assignment of an aeronautical radio frequency occurs within 60 nm of the cable system (drop-in), the cable operator would have thirty (30) days to resolve the new conflict.

Section 76.611 (47 CFR 76.611) Operation Near Certain Aeronautical and Marine Emergency Radio Frequencies.

a) cable carrier frequencies greater than ten microwatts are prohibited:

   1) within 100 kHz of the universal S.O.S. frequency 121.5 MHz.

   2) within 50 kHz of the two emergency frequencies 156.8 and 243.0 MHz.

Section 76.613 (47 CFR 76.613) Interference from a Cable System.

a) definition of harmful interence

b) responsibility of cable operator to eliminate the harmful interference.

c) Engineer In Charge (EIC) of the local field office may issue a "cease and desist" order in situations of "safety of life" and protection of property.

Waiver of Section 76.610 (47 CFR 76.610)

At the time of the writing of this paper, the FAA has indicated that they probably would not object to a waiver of Section 76.610 of the FCC's Rules if the following criteria were met.

a) the proposed usage is at least 10 nm outside the service volume of the aeronautical radio station.

b) the frequency offset is at least 30 kHz and the cable frequency stability is maintained at 5 kHz or less.

FCC Compliance

The vigorous enforcement of the reporting criteria of Section 76.610 of the rules began shortly after September, 1980. This step-up in enforcement activity was in response to the claim of the FCC's lack of enforcement of the aeronautical rules coupled by the earlier interference events.

The enforcement actions included two types of inspections (Phase I and Phase II). A Phase I inspection is described as a "paper inspection" by the FOB inspectors. In a Phase I inspection, FOB field offices are directed to randomly select cable systems for inspection. The inspectors would visit the cable systems and ask whether the system is operating in the aeronautical bands. If the system is using aeronautical frequencies, they are requested to produce documentation which would satisfy Section 76.610 of the rules. If documentation cannot be produced, the cable operator would be make aware of the violation. The inspector would be recording the usage and would submit the report to the Enforcement Branch of the CATV Bureau for forfeiture actions. While the inspectors are at the system, they are also to check for compliance with other areas of the cable rules (e.g. radiation leakage). In a Phase II inspection, the FOB inspector would actually "walk" the system and measure for leakage along the cable plant. The results are again forwarded to the CATV Bureau for follow-up actions. Usually, a Phase II inspection is selected at random by the individual field offices. However, these inspections could also be a result of an earlier Phase I inspection or triggered by complaints on the cable system.

In 1981, FOB inspected over 180 cable systems for Phase I compliance. A review of the reports indicated the following: twenty eight percent (28%) of the systems inspected that were operating within the aeronautical bands didnot report their usage to the Commission, twenty seven percent (27%) of the cable systems were not using the critical frequencies, and thirty percent (30%) of the system had complied with the reporting criteria as required by Section 76.610 of the rules.

In 1982, 285 Phase I inspections were conducted by the FOB field offices, the results of these inspections indicated that eleven percent (11%) of the

the cable systems still didnot comply with the reporting criteria of the rules, thirty four percent (34%) were not using the aeronautical frequencies and fifty five (55%) percent had reported usage.

Since the middle of 1981, there had been approximately forty Phase II inspections conducted by the FOB field offices. The resulting data indicated that only six percent (6%) of the systems had little of no leakage. Conversely over thirty four percent (34%) of the cable systems measured had leaks that would result in cumulative leakage indices of greater than 64 (refer to the Final Report of the Advisory Committee on Cable Signal Leakage released in 1979). If we were to draw our conclusion from the report, these cable systems would have a ninety percent (90%) chance of causing "harmful interference", as defined in the same report, to aircraft flying at altitudes of 1500 feet.

Since the intensification of the FOB inspections, approximately 600 cable operators had voluntarily disclosed their violation of the notification requirements in hopes of expedious processing on their frequency usage notifications. Of these 600 disclosures, at least seventy percent (70%) had to vacate certain channels within the aeronautical bands at one time or another. During that same time period, there had been close to two thousand (2000) waiver requests for frequency offset requirements of the Rules.

Up until now, the Commission had levied fines for violation of the interim rules and leakage standards to sixteen (16) cable systems. These fines total to one hundred twenty five thousand dollars ($125,000).

The Aeronautical Frequency Processing System (AFP-CABAL)

The AFP-CABAL system was originally designed to handle the voluminous number of notifications which the then CATV Bureau had to review for aeronautical conflicts. However, the exponential increase in the number of notifications and the retention of the manual files had became too tedious for the limited staff. The automation of the AFP-CABAL system would relief the laborious tasks associated with the upkeep of the aeronautical files. In addition, it would serve to complement the enforcement actions as well as give rapid responses to the various agencies that from time to time requested assistance on these cable aeronautical matters.

The main objectives of the automated system is as follows:

a) maintain a data base of all aeronautical notifications and their related actions.
b) generate responses for all aeronautical requests.
c) allow users to rapidly retrieve and/or update information.
d) permit other users access to selected information. Initially, the other FCC Bureaus and the FAA, then access on a limited basis will be available to the public.
e) automatically process aeronautical frequencies used by cable systems within the data base against changes in assignments by the FAA or DoD (drop-ins) and notify operators of the new conflicts.
f) ability to generate statistical reports as needed (e.g. so the author does not have to tabulate through the paper files as he did on this paper).

The extension of the AFP-CABAL system would ensure the other regulatory agencies and indicate to cable operators of the FCC's commitment for continuing monitoring and enforcement of the FCC's cable aeronautical rules.

WHERE IS IT GOING ?

According to statistics compiled from information filed by cable operators on FCC Form 325, as of October, 1982, there were 470,000 strand miles of cable in this country. From the same set of data, the total number of reported cable systems amounted to 5100 serving over 12,000 communities. Of these 5100 cable systems, about one-third of them indicated the use of aeronautical frequencies.

These numbers would most certainly increase as the cable television industry heads into a rebuilt period. The rebuilt systems are likely to utilize frequencies within the aeronautical and amateur radio bands. As the number of cable users in these bands increase, the likelihood of interference are also bound to increase. If cable operators are not careful, the over-the-air user groups can and will exert tremendous pressure on the Commission to ban cable operators from venturing into their frequencies. Cable operators should recognize that they are the secondary users and not the other way around. The FCC's rules at this time require cable operators to eliminate harmful interference if and when it occurs. Until cable operators can prove themselves a "closed system", they will have to appease their over-the-air counterparts. The Commission will most likely never entirely ban cable's use of the troublesome frequencies but it can make it more difficult rather than easier for cable operators.

Compromise Solutions

The issue of cable signal leakage interference to over-the-air users should be broken into two separate parts. The first and more important portion is aeronauticals and cable. It appears that all the documented cases of aeronautical interference occurred without any frequency offset between the cable carrier used at the time and the aeronautical channel. It also seems that all the cable interfering carriers are either visual or pilot carriers with peak power levels in excess of 100 microwatts (38.75 dBmV). I believe the operation of cable carriers within the aeronautical bands will probably not be a problem if the cable carrier frequencies are at all times at a constant frequency offset from the aeronautical channels (the FAA and DOD channel assignments are usually 25 kHz apart). If this offset is kept constant, then the threshold power levels can be increased to 38.75 dBmV. This will eliminate more than half of the concerned cable carriers (e.g. aural and data carriers). The best incentive of all, cable operators can lose their constant fear of drop-ins by the FAA or DOD. There is at all times an offset from the new assignments. Of course, more frequent and more diligent monitoring by cable operators will ensure the "closed system" that cable should be.

The second portion is cable and the other over-the-air users. This issue should not be too difficult to handle if the diligent monitoring program is is maintained by cable operators. Outside of keeping the cable system tight, better cooperation with the over-the-air users (especially the HAM's) will most likely to relief the present hostility between the various groups.

CONCLUSION

Peaceful co-existance between cable operators and their over-the-air counterparts can certainly be a reality provided cable operators are willing: to keep their systems tight, are willing to "give in" and slightly offset their carrier frequencies within the critical bands, and finally "talk to" and cooperate with other users on interference prevention and elimination.

ACKNOWLEDGMENTS

The author is appreciative of Clifford H. Paul for his guidance and would like to wish him a well earned and a healthy retirement. The author would also like to thank Carol Uri and Eugene Cea, both of the FCC, for their tireless efforts on the AFP-CABAL program.

REFERENCES

1) Cable Television Report and Order, (36 FCC 2d 143 (1972)).
2) Notice of Proposed Rule Making in Docket 21006, (61 FCC 2d 1022 (1976)).
3) First Report and Order in Docket 21006 (65 FCC 2d 813 (1977)).
4) Powers, Robert S. "Signal Leakage and Interference With Over-The-Air Radio Services", NCTA Technical Papers, 1977.
5) Final Report of the Advisory Committee on Cable Signal Leakage, November, 1979.
6) Further Notice of Proposed Rule Making in Docket 21006 (FCC 80-126, 76 FCC 2d 311 (1980)).
7) Powers, Robert S., Haller, Ralph A. and Adams, Jean E., "Airspace Fields Due to Signal Leakage

From Cable Television Systems", IEEE Transactions on Cable Television, Vol. CATV-5, No. 4, Oct, 1980.

8) Worth, Nicholas E., " New Services vs The FAA: A Problem in Need of a Solution.", NCTA Technical papers, 1981.

9) Amendment of Part 76 of the Commission's Rules (FCC 81-51, 76 FCC 2d 311 (1980)).

10) Markey, Gerald A. "CATV Interference to ATC Communications/Navigational Facilities" Handout to New Jersey CATV operators, June, 1982.

11) "Amendment of Part 76 of the Commission's Rules to Preclude CATV Operation of Frequencies assigned to the Amateur Radio Service", RM-4040, March, 1982.

12) Uri, Carol, "Cable Aeronautical Frequency Processing System-Requirement Study", Project No. AFP, July, 1982.

Note: Opinions and suggestions which were discussed in this paper were those of the author alone, and did not necessarily represent the position of the Federal Communications Commission.

CABLE STEREO .. PERFORMANCE AND SECURITY ISSUES

Ned L. Mountain

Wegener Communications, Inc.

Norcross, Georgia

ABSTRACT

The past three years have seen some exciting developments in audio related services to the cable industry. In previous papers (NCTA 1980 and 1981) I have given background and insight to the emerging field and many of those early predictions are starting to become reality. The purpose of this paper is to review the key technical elements regarding stereo audio transmission with special emphasis on cable plant signal degredation and security of premium audio signals.

INTRODUCTION

There are three current activity areas that are drawing cable audio to increased prominance. They are:

1. Cable Stereo TV Simulcasts - MTV was the first video service to agressively promote stereo audio as an important element of the total entertainment experience. Other services are transmitted in full stereo (The Nashville Network, The Movie Channel, The Disney Channel, all Canadian Pay TV Services, etc.) and the cable industry has come to recognize the consumer appeal of stereo TV audio. While the broadcast industry is still floundering over technical standards for TV stereo, the cable industry has provided subscribers with this service since 1981.

2. Satellite Audio Techniques - Delivery of stereo TV audio necessitated the development of satellite transmission systems that could provide high quality stereo with no impact to video quality. Two systems have emerged as dominant in this field. The Dual Subcarrier Matrix System is being used by MTV, The Movie Channel and The Disney Channel. The Wegener 1600 System is being used by The Nashville Network, all Canadian Pay TV Services, and virtually all stand-alone audio services. The Wegener 1600 system has become the "De Facto" standard for spectrum efficient satellite subcarrier transmission.

3. Audio Security - As more non-broadcast cable stereo sources become available, their perceived consumer value as a group has increased significantly. Many cable operators are exploring the idea of securing the audio package to prevent theft of service and create a new revenue stream. 1982 saw the announcement of the Wegener/ Pioneer audio security converter. This simple device allows the cable operator to transmit all premium signals outside the FM band. The audio security converter then translates the premium signals back to the FM band. Additional discussions of this device are contained later in this paper.

TECHNICAL CONSIDERATIONS FOR CABLE STEREO TRANSMISSION

Figure 1 illustrates the expected audio performance of subcarrier transmissions as received in the cable head-end. As you can see, the quality of audio signals delivered to the head-end is very satisfactory for both the conventional and Wegener 1600 systems. The left and right channel audio signals are transmitted from head-end to the subscriber with conventional FM stereo multiplex techniques. The cable distribution network is the only significant source of signal degredation.

SPECIFICATION	CONVENTIONAL SUBCARRIER SYSTEM	1600 SUBCARRIER SYSTEM
Frequency (MHz)	6.8	6.30
Deviation on Main Carrier (MHz Peak)	2.0	.95
Occupied Bandwidth (kHz)	500	130
Peak Audio Deviation (kHz)	237	50
Frequency Response (50 Hz-15 kHz)	± dB	±½dB
Peak Signal to Noise Ratio (dB)	70	70
Distortion	≤ 1%	≤ 1%

(EIRP = 33 dBW; Earth Station G/T = 21.5 dB/Deg. K)

FIGURE 1: PERFORMANCE COMPARISON OF CONVENTIONAL AND WEGENER 1600 "SPECTRUM EFFICIENT" SUBCARRIER TRANSMISSION SYSTEMS. QUALITY AUDIO IS BEING DELIVERED TO THE HEAD-END VIA SATELLITE.

Cable systems have been carrying FM signals for many years. With regard to technical performance, the cable plant is capable of providing essentially transparent transportation of these signals. This signal transparancy is true for most parameters such as frequency response, distortion, stereo separation, etc. but is not necessarily true for stereo signal to noise ratios. Due to the inefficiencies in FM stereo multiplexing, the detected stereo signal to noise ratios will range between 50 and 60 dB (unweighted) on typical cable systems. Figure 2 illustrates the detected stereo signal to noise as a function of both video C/N and FM carrier levels in dBmV. (Both measured at the subcriber drop). For best overall performance with minimal impact to system loading we recommend a -10 dBmV drop level; which implies a Channel 6 visual to FM stereo carrier ratio of 10 dB.

AUDIO SECURITY

With the advent of satellite delivered premium audio signals came the obvious need to secure such signals against theft of service. It is very difficult to scramble an FM stereo multiplex signal without degredation. In the interest of simplicity and cost, Wegener Communications and Pioneed Communications collaborated on design parameters necessary for a "stereo top" audio security converter. Since no specifications exist for such a device, we submit the specifications on page III as being the minimum acceptable for premium performance.

Several of these specifications deserve special comment.

Local Oscillator Frequency - The frequency 209.7625 MHz was deliberately chosen to allow placement of the 108-120 MHz carriers between FAA assignments in the air navagation band from 108-118 MHz. Although not mandatory if operators operate below the FAA 10^{-5} watt threshold, we consider it good engineering practice. This frequency is also 12.5 kHz above the channel 12 aural carrier. This frequency selection coupled with the -35 dBmV L.O. leakage specification at the input port will insure that no video degradation can take place to near-by TV sets. Analysis of a typical CATV feeder yields a worst case C/I ratio of better than 59 dB which is more than adequate to protect the channel 12 aural carrier frequency. A well chosen local oscillator frequency is just one small step in maximizing design. No exotic external splitters are required to implement this audio security converter concept.

Noise Figure - The noise figure specification of the Wegener/Pioneer converter is specified at 6 dB MAX. Operation in critical spectrum (108-120 MHz coupled with marginal levels necessitates that the converter contribute insignificant noise levels to the detected stereo signal. Figure 4 illustrates the effect of converter noise figure as a function of overall CATV plant parameters.

In summary, a well designed FM block converter will contribute an insignificant additional degradation to a cable FM stereo signal. Figure 5 illustrates the Wegener/Pioneer frequency allocation plan for secure audio services.

USE OF THE 108-120 MHZ SPECTRUM

Much controversy surrounds the use of 108-120 MHz for carriage of any CATV signals. It is my contention that audio services constitute a wise use of the spectrum as long as the cable systems strictly obey the FCC rules. The rules state that signals present on the system in this spectrum cannot exceed 10^{-5} watts (+28.75 dBmV at 75 ohms). The worst case level is typically at the bridger output and is typically +48 to +50 dBmV at the highest frequency of interest. With a slope of approximately 6 dB from the highest frequency of interest to 108 MHz, the maximum output of an equivalent visual carrier would be +42 to +44 dBmV. To be legal, the FM carrier must be run 13.25 to 15.25 down from the equivalent level of a channel A-1 visual carrier. Since CATV plant system designs vary, the exact point of legal threshold must be established for each system.

SUBSCRIBER DROP CARRIER LEVEL

Video C/N	0dBmV	-5dBmV	-10dBmV	-15dBmV	-20dBmV	-25dBmV	-30dBmV	-40dBmV
40	64.5 (68)	60.5 (68)	56.5 (68)	51.5 (67.5)	47.5 (66)	42.5 (62)	39 (58)	33.5 (47)
42	64.5 (68)	61.5 (68)	58.5 (68)	53 (68)	49 (66.5)	45 (63.5)	40.5 (62)	34.5 (56)
44	65.5 (68)	63.5 (68)	59 (68)	54.5 (68)	51 (66.5)	46 (65)	42.5 (63.5)	37.5 (57.5)
46	66 (68)	64 (68)	60.5 (68)	56 (68)	53.5 (67)	47.5 (65.5	44 (64)	38 (59.5)
48	66.5 (68)	64.5 (68)	61.5 (68)	57.5 (68)	53.5 (68)	49 (66)	46 (64)	40 (60.5)

FIGURE 2 DETECTED STEREO S/N RATIO - UNWEIGHTED AS A FUNCTION OF VIDEO C/N. (MONO S/N IN PARENTHESIS FOR REFERENCE) SUBSCRIBER STEREO AUDIO QUALITY IS A FUNCTION OF CARRIER INJECTION LEVEL AND PLANT C/N.

In most cases, the level will be 15 to 17 dB down from visual carrier level for legal operation without FAA/FCC coordination. I personally recommend that all CATV systems using 108-120 MHz for audio coordinate all frequencies of interest whether or not operating above or below the legal threshold. Operating without coordination of level consideration is a blatant violation of good business ethics and definitely not encouraged by the manufacturers involved.

WEGENER/PIONEER PREMIUM FM AUDIO BLOCK CONVERTER SPECIFICATIONS

Input Frequency	
Normal	88-108 MHz
Premium	108-120 MHz
Output Frequency	
Normal	88-108 MHz
Premium	88-100 MHz
Input Level	-10 dBmV Nominal
Gain	
Normal	0 ± 1 dB
Premium	10 dB ± 5 dB
Spurious Levels at Output	-60 dB Nominal -50 dB Max
Feed Through Isolation	-60 dB Nominal -50 dB Max
Noise Figure	6 dB Max
Image Rejection	60 dB Nominal 50 dB Min
Return Loss (Input & Output)	10 dB Min
Local Oscillator Frequency	209.7625 MHz
Local Spurious at Output	-15 dBmV Max
Local Spurious at Input	-35 dBmV Max
Hum Modulation	55 dB Max
Frequency Stability	± .005% Crystal Controlled
Frequency Response Flatness	
Normal	± 2 dB
Premium	± 3 dB
Operating Power	120 VAC ± 10% 60 Hz ± 10%
Temperature Range	+ 5 to 40°C
Channel Capacity (Premium)	30 Max at 400 kHz Spacing
Connectors	(3) 75 ohm "F" Female Connectors Cable Input, Tuner Output, Antenna Input
Switch Function	3 Functions: (1) Antenna (2) Regular FM, (3) Premium FM
Feed Through Isolation	
Antenna to Input or Output	60 dB
Housing Details	Pioneer BC-Series housing with tamper-proof screws
FCC Compliance	Unit meets FCC Part 15 and Part 76 radiation requirements.

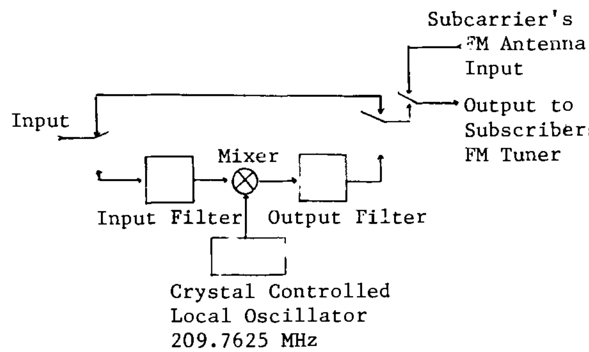


FIGURE 3: THE WEGENER/PIONEER AUDIO SECURITY CONVERTER FUNCTIONAL BLOCK DIAGRAM. LOCAL OSCILLATOR FREQUENCY IS DISCUSSED IN THE ABOVE TEXT. NOTE ABILITY TO PATCH SUBSCRIBERS OFF AIR ANTENNA TO ELIMINATE NECESSITY OF A/B SWITCH.

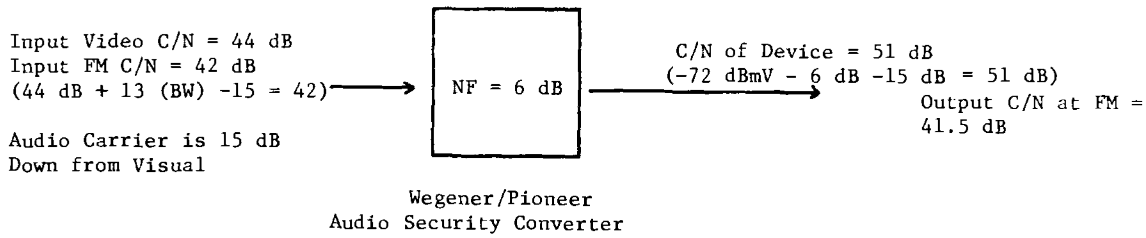


FIGURE 4: EFFECT OF CONVERTER NOISE FIGURE AT TYPICAL OPERATING LEVEL. CONVERTER DEGRADES STEREO S/N BY .5dB IN THIS EXAMPLE.

Ch. Designator	Cable Freq.	FM Output Freq.	Ch. Designator	Cable Freq.	FM Output Freq.
PW1	108.0625	101.7	PW31	114.0625	95.7
PW2	108.2625	101.5	PW32	114.2625	95.5
PW3	108.4625	101.3	PW33	114.4625	95.3
PW4	108.6625	101.1	PW34	114.6625	95.1
PW5	108.8625	100.9	PW35	114.8625	94.9
PW6	109.0625	100.7	PW36	115.0625	94.7
PW7	109.2625	100.5	PW37	115.2625	94.5
PW8	109.4625	100.3	PW38	115.4625	94.3
PW9	109.6625	100.1	PW39	115.6625	94.1
PW10	109.8625	99.9	PW40	115.8625	93.9
PW11	110.0625	99.7	PW41	116.0625	93.7
PW12	110.2625	99.5	PW42	116.2625	93.5
PW13	110.4625	99.3	PW43	116.4625	93.3
PW14	110.6625	99.1	PW44	116.6625	93.1
PW15	110.8625	98.9	PW45	116.8625	92.9
PW16	111.0625	98.7	PW46	117.0625	92.7
PW17	111.2625	98.5	PW47	117.2625	92.5
PW18	111.4625	98.3	PW48	117.4625	92.3
PW19	111.6625	98.1	PW49	117.6625	92.1
PW20	111.8625	97.9	PW50	117.8625	91.9
PW21	112.0625	97.7	PW51	118.0625	91.7
PW22	112.2625	97.5	PW52	118.2625	91.5
PW23	112.4625	97.3	PW53	118.4625	91.3
PW24	112.6625	97.1	PW54	118.6625	91.1
PW25	112.8825	96.9	PW55	118.8625	90.9
PW26	113.0625	96.7	PW56	119.0625	90.7
PW27	113.2625	96.5	PW57	119.2625	90.5
PW28	113.4625	96.3	PW58	119.4625	90.3
PW29	113.6625	96.1	PW59	119.6625	90.1
PW30	113.8625	95.9	PW60	119.8625	89.9

FIGURE 5: THE WEGENER/PIONEER FREQUENCY PLAN FOR PREMIUM AUDIO SERVICES.

CONCLUSIONS

The field of cable audio marches on! -- drawn by the marketplace.

- Satellite technology is in place today to allow premium stereo audio signals to be delivered to the head-end.
- The use of FM stereo multiplex on cable provides reasonable quality with minimum cost.
- The block converter for audio security provides a simple and effective means for cable operators to secure the premium audio signals. Block converters must be used properly and LEGALLY since sensitive spectrum is being used.

The future of cable audio is bright! Within the next 2 years, we will see even more exciting developments in both hardware and software to allow the cable industry to provide what it does best -- entertainment diversity!

CAN OPTICAL FIBER COMPETE WITH COAXIAL CABLE?

Garold S. Tjaden

COX CABLE COMMUNICATIONS, INC.

ABSTRACT

This paper concentrates on two major issues in comparing the optical fiber and coaxial cable media:

1. the relative capability of delivering a wide range of telecommunication services, and

2. comparison of the cost-effectiveness of the resulting coaxial network with the most likely future alternative, the switched optical fiber network.

It is shown that the coaxial cable medium has certain natural advantages over the switched approach which lead to significant cost advantages for the coaxial medium.

INTRODUCTION

There are currently over 600,000 miles of coaxial cable plant passing over 50 million homes in the United States. It is projected that about 50,000 miles of new plant will be added in each of the next few years, with new construction tapering off substantially by 1988 or 1989 as all major markets are wired. It appears that existing plant is being rebuilt at the rate of about 20,000 miles per year (1).

Since the outside plant of a CATV system is expected to have a ten to fifteen year useful life, cable operators must deal with the following serious business issues:

1. How can profitable growth be achieved with the existing large base of relatively new embedded plant?

2. Is there a different medium that should be used for future new or rebuilt plant that will lead to a more profitable future?

Although industry growth, and growth of certain cable companies, can be achieved over the next few years by marketing existing cable services to the new homes passed, growth beyond this time frame would seem to depend upon developing additional revenue streams. Since franchising competition has led to larger capital investments per subscriber than a few years ago, new revenue streams are probably required just to achieve traditional returns for new systems.

This paper assumes that the revenue streams of interest are most likely to come from enhanced telecommunication services having wide appeal. Delivery of such services would result in using the CATV plant as the local loop of a wideband integrated telecommunications network. Specifically not discussed here is reduction of the operating cost side of the profit equation for current CATV services. This author is unaware of any way in which using a medium other than coaxial cable would lead to such cost reductions. Indeed, the cost-effectiveness comparison presented later would indicate that operating costs would be likely to rise for other media.

BACKGROUND

A traditional cable television system has three major components, as shown in Figure 1. The hub, or headend, is the central collection point for all signals. These signals are combined and sent out over the coaxial cable plant, eventually reaching subscribers' homes where they are converted in frequency by the home terminal unit (also called a converter) for reception by the customers' television set.

The cable plant fans out from the hub in a tree fashion, splitting and resplitting until all homes are passed. This topology, called tree-and-branch, is characterized by the fact that all of the signals on the plant, or at least on each trunk, pass all of the homes served by that trunk and its branches. Thus, all bandwidth on a trunk is shared by all of the homes served by the trunk.

A cable system built within the last few years will use distribution plant capable of delivering high quality television signals to all homes served using signal carrier frequencies up to at least 400 MHz, with 440 MHz being even more typical recently. Downstream signals (hub to home) are typically carried on frequencies above 50 MHz, with frequencies from 88 MHz to 108 MHz set aside for broadcast FM radio. Such modern systems will also have amplifiers installed to carry signals in the upstream direction (home to hub) in the frequency range of 5 MHz to 30 MHz. As mentioned previously, some cable systems are being constructed with two such cables.

It is the outside plant portion of the cable system with which this paper is primarily concerned. The efficiency of this plant is related to the installed cost and the maintenance costs. In typical urban residential areas currently under construction, there are about 100 homes per mile of cable plant, and about 20% of the cable will require construction underground. Installed costs in 1982 dollars for such plant were about $12,000 per mile for aerial plant, and $20,000 per mile for underground plant. Thus, the average plant cost for each home passed by the cable was about $140. This includes full activation of the plant for two-way carriage of signals (about $1,000 per mile) and equipping the plant with standby power for the amplifiers. Maintenance costs for such plant are in the range of $5 per home passed per year.

The two-way capabilities of CATV plant have received relatively minor usage. The primary applications to date have been for impulse pay-per-view on the "Qube" system developed by Warner/Pioneer, and for residential security alarm monitoring with technology developed by TOCOM, Inc. and others.

Although the details differ, both of these applications are similar in that communications over the cable network is done using a polling protocol. That is, data messages are sent downstream (frequency multiplexed with all the other signals) addressed to individual home terminal units by a computer interfaced to the cable plant, and a data response is sent upstream by the terminal unit indicating its status. Although polling protocols are relatively inefficient in utilizing channel capacity, for these applications and the bandwidths available the efficiencies achieved are satisfactory.

One of the factors motivating the use of polling protocols has been a fear that noise on the upstream frequencies would be severe because the noise on each branch (or split) of the network will be additive in the upstream direction. The approach to dealing with this characteristic of tree-and-branch networks has been to activate only a single upstream path through the tree at a time using what is called a bridger switch. These are switches placed in the upstream inputs of each bridger amplifier which allow the signals from only one input to be applied to the upstream amplifier. The closure of these switches can be synchronized with the polling of terminal units, thereby limiting the upstream noise while maintaining continuity. Unless these switches are made frequency sensitive (switchable filters) all usage of upstream frequencies would have to be synchronized to the polling rate, a severe restriction.

PACKET SWITCHING ON A CATV NETWORK

Current activity in the development of two-way interactive services is primarily focused on the area of videotext. Cox Cable Communications has developed a cable-based videotext system called INDAX (2, 3) short for INteractive DAta eXchange. This system is a packet switched data communications system, adapted for the CATV medium to implement the control and delivery of a combination of video, teletext, and transaction videotext services.

Two-way communication uses a multiple access protocol called CSMA/CD. Forty data channels, each 300 KHz wide, are used in each direction. Data is transmitted at a rate of 28 KB. Home terminal units provide the functions of a normal converter for delivery and control of video entertainment, and implement the functions of data transmission and reception, and display of this data in the form of graphics and text on the customer's TV set. The data modems are frequency agile, and can tune over the entire forty data channels. Traffic modeling indicates that INDAX could satisfy the videotext demands of a typical 125,000 home city using only three to six data channels.

Field operation has verified that a CATV network provides an excellent medium for packet switched data communication. The Bit Error Rate (BER) of data is directly related to the modulation technique used and to the carrier-to-noise ratio (C/N) at the receiver input. In the CATV environment, the FCC requires that the video signal measured across a 4 MHz bandwidth shall not be less than 38 dB C/N. Each INDAX data channel occupies a 300 KHz bandwidth, giving a 13 dB C/N improvement over the 4 MHz video C/N. Experiments indicate a 10^{-8} Bit Error Rate (BER) with a C/N of 20 dB. In order to meet FAA signal requirements, INDAX signals are carried 16 to 20 dB below normal video signal levels, leaving more than 10 dB headroom. The upstream C/N ratio is much more difficult to project because of the tree configuration creating the noise funneling effect previously discussed. It has been found that upstream signals should be carried at a level approximately equal to that of the return video level. Field measurements indicate that the C/N of an upstream plant with 200 miles of active cable is approximately 45 dB. Bridger switching has been found to be necessary only to isolate a branch in the event of catastrophic ingress. In such a case the bridger switch would be opened only for the leaky branch so service could be continued to all other subscribers.

SWITCHED VOICE ON A CATV NETWORK

The most straightforward way to provide switched voice (plain old telephone service) on a CATV network would be to dedicate an upstream/downstream voice channel pair for each service unit. Assuming 5 KHz voice signals and amplitude modulation, a 20 KHz voice channel should provide adequate channel isolation. A single 400 MHz coaxial cable configured so that equal bandwidth is available in each direction would provide about 8500 voice circuits. Since the maximum number of homes passed by a single trunk run is about 8000, residential switched voice capability could conceivably be provided with a single cable network for an installed outside plant cost of about $140 per service unit.

Current telephone systems take advantage of the fact that individual telephone lines are used only for a small fraction of time in any given time interval to reduce the cost of switching by equipping the switches to be able to connect only a fraction of the lines at any instant of time. These same usage patterns can be used to reduce the bandwidth required to deliver switched voice on a coaxial cable network.

Residential telephone systems are engineered to be able to handle a load of 3 CCS per line in the peak busy hour (CCS means "hundred call-seconds"). That is, on the average, each line will be busy for 300 seconds during this peak hour. A CATV trunk serving the maximum of 8000 units must then carry a worst case load of 8000 x 3 CSS = 24,000 CCS per hour, or 24,000/3600 = 6.67 CCS per second. This would be the load if all calls were evenly distributed over the hour. To account for the fact that instantaneous peaks in the load can occur, it is common, as a rule of thumb, to multiply by two to find the peak instantaneous load. Thus, the maximum number of voice circuits required to serve the load of 8000 service units is 2 x 6.67 x 100 = 1334 circuits. At 20 KHz of bandwidth per circuit, about 27 MHz of bandwidth in each direction of each CATV trunk would suffice. This bandwidth is less than the equivalent of five NTSC video channels in each direction.

Implied in this approach to delivering switched voice service over a CATV network is that electronic telephone sets having frequency agile modems are used. One would expect that the signaling required to establish connections would be done on a separate signaling channel, perhaps using a CSMA/CD protocol. The connection would be established by assigning each telephone set to an upstream/downstream voice channel pair. Inter-trunk or inter-hub switching would be accomplished by frequency translation between cables. To the author's knowledge such switching and modem technology for this approach to switched voice does not exist. However, the technology developed for the INDAX packet switched network is very similar, indicating that such technology could be feasible. The technology of cellular radio is also very similar in concept to that proposed here, again indicating feasibility.

Since bandwidth is relatively plentiful on a coaxial cable medium, it may be interesting to carry digital rather than analog voice as the overall system cost may be less. Using a form of DPCM at perhaps 32 KB, digital voice channels should fit quite comfortably into 60 KHz. In this case, three times the bandwidth, or 81 MHz in each direction, would be required for an end-to-end digital service. It may also be interesting to explore the use of a few high speed digital voice channels in conjunction with a TDMA protocol as a yet more optimal system design.

Privacy of communications can be an issue in a tree-and-branch system since the signals are available to every service unit. The opportunities for monitoring all communications, are, therefore, greater than in a conventional telephone system. Such privacy concerns are as important for data communications as they are for voice. Privacy is relatively easy to ensure for signals in the digital domain using various encryption approaches. Digitized voice, would of course, be amenable to such techniques. If conserving bandwidth were an issue for voice communications an approach in which voice is digitized, encrypted, and then converted back to analog for transmission could be considered.

OPTICAL FIBER ALTERNATIVES

Optical fiber does not lend itself to use with a tree-and-branch topology because of the difficulty of splitting and tapping signals. It is more appropriate for use in a "star" topology, in which a fiber would be run between each service unit and a central switching point. This star topology is employed in current telephone systems in the local loop plant.

In a star telecommunications system, each service unit has the bandwidth available on a loop (copper twisted pair or optical fiber) dedicated to it. As discussed earlier, this loop is idle much of the time. As a benchmark of comparison, the tree-and-branch CATV system in Omaha uses about 1200 miles of coaxial cable to pass all 125,000 homes. Four hubs are required. A star approach to wiring this city would require over 82,000 miles of optical fiber (assuming bidirectional communication on a single fiber) if fourteen hubs (switching points) are used to keep the loop length to a maximum of 2 Km.

Outside plant costs for star systems using copper twisted pairs are well known, averaging about $400 per service unit. Local loop optical fiber networks are not in commercial operation, so only estimates can be made of their costs. Indications are that an optical fiber star local loop network would not be less expensive in installed costs, at least through 1990 (4, 5, 6), than current copper twisted pairs.

Most of the current work on approaches to using fiber optics in the local loop seem to involve a hybrid topology which uses long runs of multiplexed signals from central switching centers to remote switches located within a few thousand feet of service units. Dedicated fiber pairs are then used from the remote switches to service units. The most aggressive estimate known to this author of future installed outside plant cost for such an optical fiber hybrid is $350 per service unit (6). The major cost justification for such a system is proposed to be in reduced annual maintenance costs. Such costs are estimated to be some 50% (6) to 80% (5) lower for optical fiber than copper twisted pairs. Current copper twisted pair maintenance costs are about $100 per service unit per year (6).

An optical fiber local loop network using a pure star topology would have sufficient bandwidth from the service unit to central hub to offer all contemplated services, including real time video-on-demand and real time switched point-to-point video. Certainly all broadcast type video and audio services, as well as switched and dedicated data services could be supported. However, a hybrid optical fiber network would be capable of supporting only limited video-on-demand and point-to-point video services because of the bandwidth limitations of the multiplexed run from the central hub to the remote switches.

CONCLUSIONS

Optical fiber integrated wideband local loop networks appear to have future outside plant installed costs of about $350 per service unit with annual maintenance costs of about $50 per service unit. Such networks could deliver all wideband services; except video-on-demand and switched point-to-point video services would be limited to relatively low usage levels.

A single 400 MHz coaxial cable local loop network could deliver virtually the same services as a hybrid optical fiber network. Sufficient bandwidth is available to deliver some forty channels of video entertainment programming, switched voice, switched data, and limited video-on-demand, switched point-to-point video, and dedicated channel data. Current outside plant installed costs are about $140 per service unit with annual maintenance costs of about $5 per service unit. It should be noted that equipment costs for such plant have been falling, while labor costs have been rising. Labor costs will rise independent of the medium, and on a service unit basis should bear the same relative relationship over time for the coaxial cable and optical fiber media.

Thus, coaxial cable would appear to be a significantly better investment than optical fiber for integrated wideband local loops. This is not to say that optical fiber has no useful role in a local distribution system. Indeed, it is currently a more cost-effective medium than coaxial cable for certain dedicated interconnect situations in CATV systems. One would expect that other such niches will be found for optical fibers and the future will see a blending of it with coaxial cable as the optimal solution in specific situations.

REFERENCES

1. "MSO Construction Plans," Cable Marketing, December 1982.

2. M. L. Ellis, G. W. Gates, and G. S. Tjaden, "INDAX: An Operational Interactive Cable Television and Home Information System," Proceedings of COMPCON Spring '82, pgs. 356-359.

3. M. L. Ellis, G. W. Gates, etal., "INDAX: An Operational Interactive Cabletext System," IEEE Journal on Selected Areas in Communication, SAC-1, no. 2, February 1983, pgs. 285-294.

4. France Telecom, private communications.

5. Yankee Group, draft of report: "Segmentation Strategies, Part II: AT&T and the Home Service Bureau," July, 1982.

6. Southern Bell, private conversation.

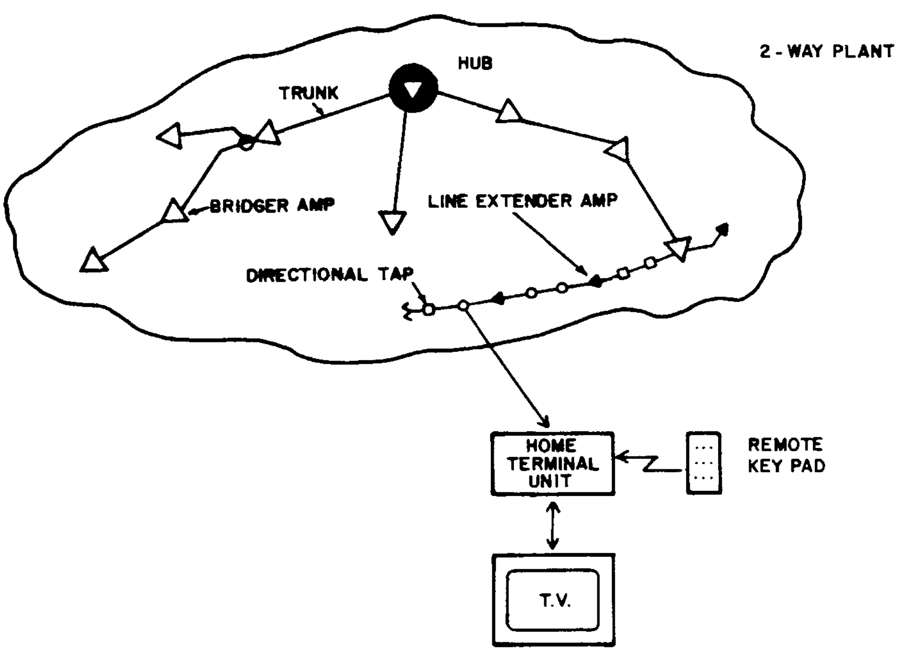


FIGURE 1: CATV NETWORK FOR VIDEO ENTERTAINMENT

CHARACTERISTICS AND PERCEPTIBILITY OF CROSS MODULATION

Rezin Pidgeon, Jr.

SCIENTIFIC-ATLANTA, INC.

ABSTRACT

Results of a study to determine the measure and perceptibility of cross-modulation distortion in a CATV system are presented. Subjective tests evaluate the interference to a television picture or test pattern caused by one to 24 independent video-modulated carriers. Design of the test system enabled cross modulation to be measured and observed without being obscured by triple-beat distortions. Although cross modulation is not a predominant factor, it is of more concern in a phase-locked system because of suppression of triple-beat distortion.

Cross modulation can result in both AM and PM components. In distribution amplifiers, the PM component may be the larger of the two, particularly at the higher cha nel frequencies, although generally only the AM component is measured. In these tests, the AM and PM distortion components are measured separately and the relative importance of each is shown.

INTRODUCTION

Cross modulation (crossmod) is a type of distortion that was particularly noticable in earlier CATV systems. It is characterized by the "windshield wiper" effect or interference appearing as frames or images slipping in the TV picture. As advances were made in amplifier performance and the number of channels increased from 12 to 62 or more at present, triple-beat distortion increased in relative importance. For cross modulation the distortion is closely proportional to the number of channels, whereas for triple-beat distortion, the effect increases rapidly as the number of channels increases. For wide-band systems, triple-beat distortion is the major contributor to the total distortion.

To extend the performance of newer wide-band systems phase locking came into being. This technique reduces triple-beat interference and enables system operating levels to be increased 4 - 5dB. Thus, with phase locking the relative importance of cross modulation is increased.

This paper presents results of experiments made to measure the amount of cross modulation that is just perceptable in a TV picture. Relatively little data has been found on the subjective measurement of cross modulation, partly because of the difficulty in separating other distortions from cross modulation and observing only cross modulation. The experiment described herein generates cross modulation by direct video modulation instead of by distortion in a cascade of amplifiers. This enables cross modulation to be controlled and observed without other impairments.

The following sections review the basic characteristics and measurement of cross modulation. The experiment is described and results are presented.

CROSS-MODULATION ANALYSIS

Amplifier distortion has been treated extensively in the literature, and distortion effects in CATV amplifiers are well understood. However, to aid in the discussions that follow a few of the basic equations and definitions are given in the following paragraphs. This simplistic treatment is presented to show the characteristics of cross modulation and distinguish it from other distortions, particularly those in which modulation sidebands occur because of modulation of carrier "beats".

If the amplifier nonlinearity is expressed by the first three terms in a power series [1], then

$$e_{out} = k_1 e_{in} + k_2 e_{in}^2 + k_3 e_{in}^3. \quad (1)$$

The coefficients k_1, k_2, and k_3 are the linear gain and second- and third-order distortion coefficients, and are real constants if we assume no phase or frequency-dependent distortion*. The input voltage is first assumed to consist of three sinusoidal voltages or carriers

$$e_{in} = A\cos W_a t + B\cos W_b t + C\cos W_c t. \qquad (2)$$

The distortion produced at carrier frequency Wa is obtained by expanding (1) and collecting all terms containing Wa. Thus

$$e_{(W_a)} = (k_1 + 3/4\ k_3\ A^2)A\ \cos W_a t + 3/2\ k_3\ (B^2 + C^2)A\ \cos W_a t. \qquad (3)$$

The first term contains a distortion term $3/4\ k_3A^2$ which represents self-compression or self-expansion (depending on the sign of k_3). This term is identically the same whether or not other signals are present and can be neglected since certainly the system must amplify a single channel faithfully. The term $3/2\ k_3(B^2 + C^2)A\cos W_a t$ is the cross modulation component. This shows that for CW carriers the carrier at W_a is compressed or expanded by carriers at W_b and W_c regardless of their frequency. Thus, cross modulation is inherently different in origin from distortion caused by "beats" or mixing of carriers.

Only the linear and cross modulation terms are given in (3). A complete third-order expansion would give the following terms: (1) a dc term, (2) a linear term (desired component), (3) cross modulation terms, and (4) harmonics and "beat-frequency" terms (sum and difference frequencies including $2W_a \pm W_b$, $W_a \pm W_b \pm W_c$, etc.). This latter group is the major cause of distortion or interference to the TV picture. Carrier systems that are not phase locked are limited by carrier beats, primarily composite triple beat, at higher operating levels. In phase-locked HRC systems all video-carrier beats are coherent with the picture carriers, and in this case interference is caused by the modulation present on each beat. This effect may be called "beat modulation", and is different in origin but similar in appearance to cross modulation.

---

*A more rigorous treatment is obtained by a Volterra series expansion [2]. With the power series expansion it is assumed that the output signal depends only on the input signal at the same instant of time. The volterra series expansion treats the case of frequency-dependent nonlinear characteristics. Similar results are obtained for cross modulation except for changes in magnitude and phase of the distortion components.

The above equations are given for CW (unmodulated) carriers, but also apply for modulated carriers. The carrier amplitudes A, B, and C can be video-modulated amplitudes $A(t)$, $B(t)$, and $C(t)$. Rewriting equation (3), cross modulation distortion is

$$XMOD = 3/2\ k_3(B^2{}_{(t)} + C^2{}_{(t)})A_{(t)}\cos W_a t \qquad (4)$$

Since cross modulation is porportional to the amplitude of the interfered carrier $A(t)$ cross modulation will be larger in the darker areas of the TV picture. Note also that crossmod is proportional to the amplitude squared ($B^2(t)$ or $C^2(t)$) of the interfering signals.

The above discussion relates to amplitude cross modulation (amplitude modulation of the desired carrier). Cross modulation can also appear as phase cross modulation. Due to amplifier phase shifts and nonlinearities, amplitude modulation is converted to phase cross modulation. In addition, at higher frequencies the nonlinear transistor junction capacities become significant contributors to phase crossmod [3]. The presence of both amplitude and phase cross modulation has caused some confusion in the measurement, specification, and subjective effects of cross modulation [4].

Phase modulation of the TV signal becomes visible since phase crossmod results in frequency modulation, and FM is slope detected by the Nyquist filter in the TV receiver [4]. Since the instantaneous frequency is proportional to the derivative of phase, light-dark and dark-light transitions in interferring TV pictures (particularly leading and trailing edges of sync bars) produce large frequency deviations and will be seen as lines of interference. Components above the Nyquist slope (more than 600 KHz above the picture carrier) are detected equally whether phase or amplitude modulated.

CROSS-MODULATION MEASUREMENT

Cross modulation can be measured by different techniques and under various conditions. Equipment manufacturers and system designers measure and specify cross modulation by the familar "NCTA method". NCTA Standard 002-0267 "CATV Amplifier Distortion Characteristics" [5] defines and specifies this measurement. In this procedure all carriers except the one in question are square-wave modulated at the horizontal line rate. The level of modulation impressed on the observed carrier is then measured, usually by tuning a spectrum analyzer to the carrier, turning the IF sweep off, and measuring the linearly-detected envelope with a waveform analyzer tuned to 15.75KHz.

Cross modulation is also measured by measuring sideband levels with a spectrum analyzer [6]. This technique is useful for observing interference, but results will correlate with the NCTA measurement for only amplitude modulation and if beats do not obscure the 15KHz cross modulation sidebands. Since for 100% square-wave modulation the first sidebands are 10dB below the peak level, the NCTA measurement is 10dB greater than the 15KHz sideband level. Note however, readings can be effected by second- and third-order carrier beats. For example, if the carrier being observed is turned off, a cluster of beats (if the carriers are not phase locked) will be seen centered at the carrier frequency. If all carriers are modulated, clusters of sidebands due to modulation of individual beats will also be observed. These beats add noise to the carrier being measured (the carrier is not modulated by the beats), but the noise is rejected by narrow-band filtering if a wave analyzer or synchnouous demodulator is used in the NCTA procedure.

TEST SYSTEM

The subjective measurement of cross modulation perceptibility is difficult because of the presence of other distortions. A method of observing picture degradation in the presence of composite-triple-beat noise and with or without cross modulation has been reported [7]. This method allows crossmod to be eliminated from the observed distortion, and thus one can ascertain whether crossmod is a significant contributor to the total distortion in a particular system. However, crossmod cannot be observed with complete freedom from other distortions since they are generated by the same amplifier nonlineariies. Therefore, a method of simulating crossmod was devised and implemented. Furthermore, with this method cross modulation can be generated by either AM or PM (or some of each). The procedure is simply to add some interfering modulation to a normal video-modulated carrier and observe the result in the TV picture. Independent video sources are used to create the interference and the measurement is then related to crossmod as measured by the NCTA procedure. Note that for the simulation to be an accurate representation, equation (4) requires that the distortion be porportional to (1) the amplitude of the interfered carrier $A(t)$, and (2) the amplitude squared of each interfering video source ($B^2(t)$, etc.). The method for accomplishing this is illustrated in Figures 1 and 2.

The video picture or test pattern to be observed is connected to the video IF modulator of a Scientific-Atlanta 6350 Television Modulator. The video interfering signals are coupled to individual circuits which dc restore and square each signal. The outputs of the squaring circuits are then summed and ac coupled to the modulation input of an IC modulator. The RF input to the modulator is a sample of the video-modulated IF. The output of the modulator is the form

$$A(t)\,[B^2(t) + C^2(t) + \ldots N^2(t)]\cos W_{if}t,$$

which is the proper representation for cross - modulation distortion produced by N channels. This signal is attenuated, phase shifted by the line stretcher, and combined with the video-modulated signal to be observed. The line stretcher is used to adjust the phase of the cross modulation relative to the undistorted IF so as to produce AM or PM cross modulation. For amplitude crossmod, the relative phase is 180° in order to produce signal compression.

The IF modulated signal is then processed by the vestigal sideband filter and upconverted to channel 4. The composite signal is then viewed on a TV receiver. The amount of cross modulation is attenuated and the measured cross modulation is correlated with observer reactions.

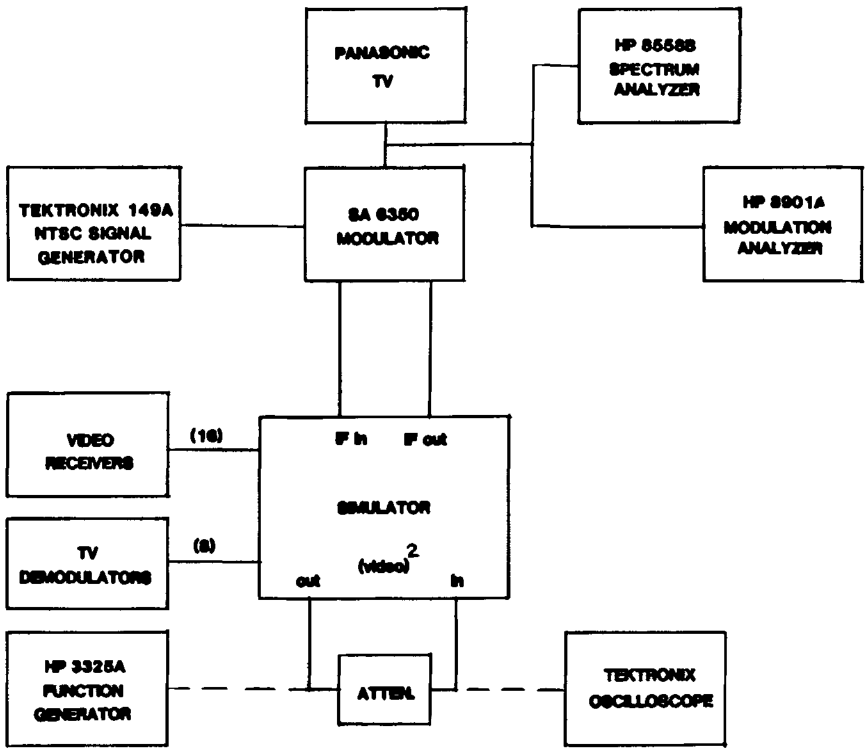


Figure 1. Cross-Modulation Test Set-Up

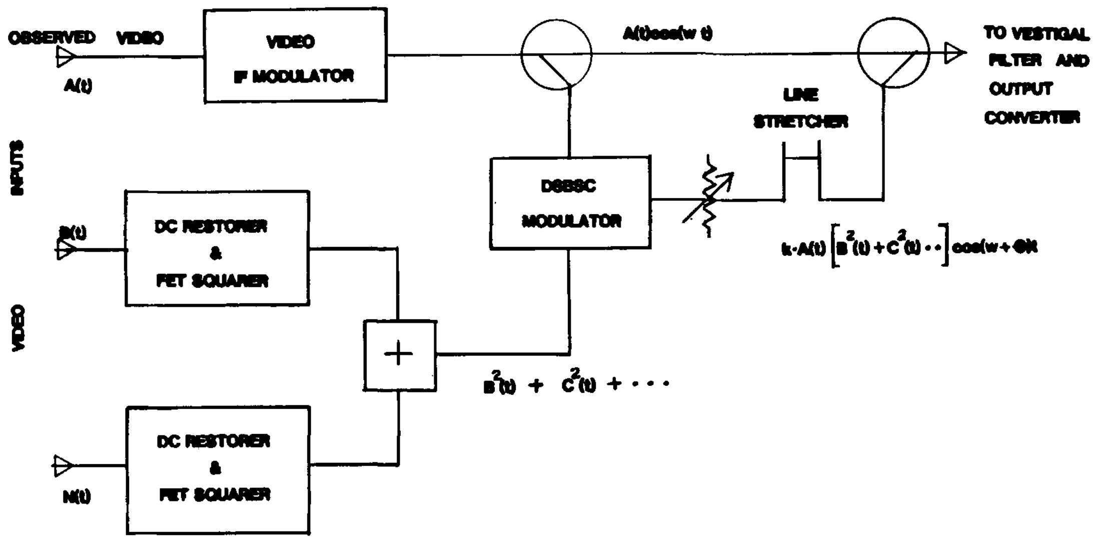


Figure 2. Cross-Modulation Simulator

TEST RESULTS

Cross modulation was measured for interference against a test pattern background. Observations were made when using TV programming material, but the large variations and movements in actual scenes made it difficult to determine the threshold for cross modulation visibility. Since cross modulation is most noticeable in a dark background, a gray flat field of 7.5 - 10 IRE was used in this experiment. The TV receiver was a Panasonic CT9051, and was viewed in dim lighting. The picture was clean - the carrier-to-noise ratio was greater than 55dB. These conditions lead to a measurement much more sensitive than would be obtained - if one could do so - under actual field conditions with live scenes and inherent noise and distortions.

Data is presented as a function of the number of video sources: 1, 2, 4, 6, 12, 18, and 24. These were independent sources; eight from local broadcast stations and sixteen from satellite receivers. For each measurement, the flat field was first viewed with strong interference, and then the cross modulation was reduced until it was barely visible. The measurements thus obtained were related to the NCTA measurement by substituting a 1V peak-to-peak 15.75 KHz square wave for each video source and measuring sideband levels on a spectrum analyzer. Adding 10dB to the 15KHz sideband levels gives the NCTA measurement.

The same procedure was used for both amplitude and phase cross modulation. Although the NCTA method is specifically for AM, it is meaningful to express phase cross modulation in the same terms by converting the measured PM to the equivalent AM. (For pure AM or low mod. index PM, as is the case here, one cannot distinguish between the two from a spectrum analyzer display). Thus, for phase cross modulation, the 15KHz sidebands were determined and 10dB added to give the equivalent NCTA number.

Results of the experiment are shown in Figure 3. For a single interfering channel the data averaged -50dB for AM and -43dB for PM. Cross modulation from a window test pattern averaged -51dB for AM and -44.5dB for PM. For 15.734KHz square-wave interference (equivalent to 100% modulation) the threshold was -59dB for AM and -52dB for PM. Thus, 100% square-wave modulation was more discernable by 7 - 8dB.

As the number of video sources increased the difference in amplitude between square-wave sources and the composite of the video waveforms increased. For a large number of video sources, the signals combine in a somewhat random manner resulting in substantially lower peak energy than for synchronous modulation. For 24 video sources, the measured cross modulation threshold averaged -35dB for AM and -26dB for PM. The difference between 100% synchronous square-wave modulation and video modulation is 24dB in AM cross modulation perceptibility.

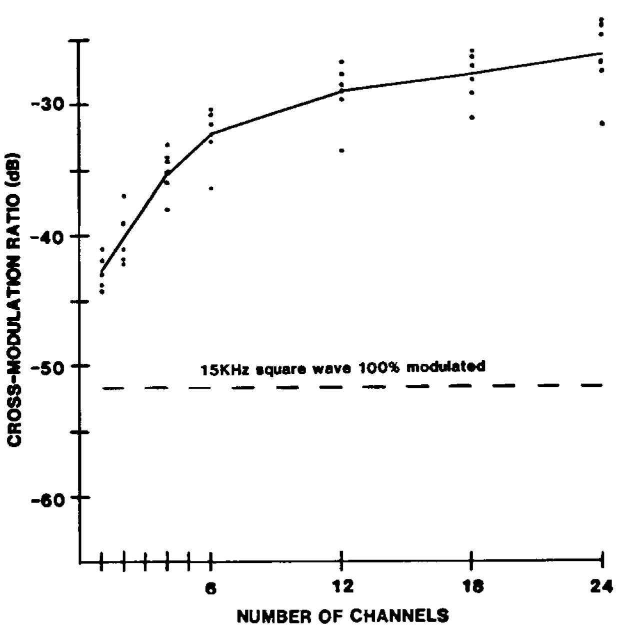


Figure 3A. Phase Modulation

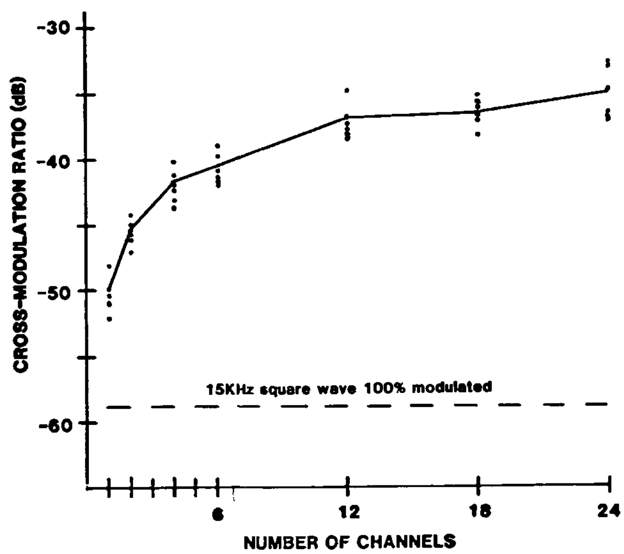


Figure 3B. Amplitude Modulation

Figure 3. Threshold of Cross-Modulation Visibility

The threshold level of cross modulation derived in this experiment is high compared to standards in general use in the CATV industry. From the trend of the data in Figure 3 we would expect a present-day channel loading of 52-62 channels to have a visibility threshold of about -32 to -34dB in a picture free of noise and other distortion. It is generally agreed that triple-beat distortion is just perceptible for a CTB ratio of -46 to -48dB* in systems not phase locked. For HRC phase-locked systems operating levels can be increased 4 - 5dB, resulting in a CTB threshold of approximately -38dB [9]. Thus, a cross modulation threshold of -33dB is 5dB higher than the CTB threshold. Amplifier cross modulation ratios are usually within a few dB of each other at their worst channels. For example, for the TRW CA5000 hybrid operating at 46dBmV, 6dB tilt, and 52 channel loading, the CTB is -67.6dB at 400 MHz and cross modulation (predominately AM) is -68.6dB at 54 MHz; CTB is higher by 1dB [10]. Since these are both third-order distortions the same difference should exist at higher operating levels: if the CTB ratio is increased to -38dB, cross modulation should be -39dB. From these numbers we conclude that triple-beat distortion in a phase-locked system is 6dB higher than cross modulation distortion.

The fact that triple-beat distortion is the predominant factor in phase-locked systems as well has been demonstrated and reported elsewhere [7]. We also reached the same conclusion in a similar experiment and also in other different tests. The objective of this paper was to quantify the measurement of AM and PM cross modulation distortion so its relative importance could be evaluated and compared by others and in other situations.

---

*This is the ratio that is measured if video-modulated carriers that produce just visible distortion are replaced with CW carriers at the same peak level, and the CTB ratio measured by the NCTA method [8]. For CW beats the ratio usually quoted varies from -51 to -57dB.

REFERENCES

1. Keneth A. Simons, "The Decibel Relationships Between Amplifier Distortion Products", Proc. IEEE, Volume 58, pps. 1071 - 1086, July 1970.

2. K.Y. Chang, "Intermodulation Noise and Products Due to Frequency Dependent Nonlinearities in CATV Systems", IEEE Trans. on Comm., Volume COM-23, pps. 142 - 155, January 1975.

3. G. G. Luettgenau, "Cross-Modulation In HRC Systems", 30th Annual NCTA Convention Technical Papers, pps. 67 - 72, 1981.

4. Linley Gumm, "Phase Effects in Cross-Modulation", IEEE Trans. on Cable Television, Volume CATV-1, pps. 5 - 10, October 1976.

5. National CAble Television Association, Standard Number NCTA-002-0267, "CATV Amplifier Distortion Characteristics", (undated).

6. Hewlett-Packard Co., Cable Television Systems Measurements Handbook, January 1977.

7. Michael F. Jeffers, "Technical Considerations for Operating Systems Expanded to Fifty or More Television Channels", 29th Annual NCTA Convention Technical Papers, pps. 1 - 4, 1980.

8. National Cable Television Association, Standard Number NCTA 008-0477, "Standards of Good Engineering Practices for Measurement on Cable Television Systems", 1977.

9. Rezin Pidgeon, Jr., "Performance of a 400 MHz, 54 Channel, Cable Television Distribution System", 31st Annual NCTA Convention Technical Papers, pps. 60 - 65.

10. G. Leuttgenau, Robert Keasler, "Hybrids for 52 Channel CATV Systems", International TV Symposium Convention Record, Montreux, Switzerland, 1981.

CLOSED CAPTIONING WITH THE LINE 21 SYSTEM

Sharon Earley

NATIONAL CAPTIONING INSTITUTE, INC.

ABSTRACT

Closed captioning has enabled the hearing impaired to enjoy television more fully over the past three years. Although over-the-air broadcasters have provided the bulk of closed-captioned programs, the participation of the cable industry is both growing and promising. The Line 21 system, with its proven transmission and reception strengths, is an ideally suited caption delivery system for cablecasters. The Line 21 signal passes intact over satellite and cable. It can be recorded in three-quarter and half-inch formats, and no special accommodations are required to retransmit it. Decoding devices, specifically designed for cable, are currently available, as is a system which enables a local operator to caption its own programming in a cost-effective manner. The National Captioning Institute sees the full participation of cablecasters in the provision of closed captions as an important step in increasing the access of the hearing impaired to television programming.

CLOSED-CAPTION SERVICE

For the past three decades, television has been a primary medium of communication for most Americans. It has become our major source of information about the world and our principal source of entertainment. But for many years, television's voice remained distorted, muted or totally silent for some 16 million Americans with impaired hearing. The situation changed in March, 1980, when the Public Broadcasting Service and the ABC and NBC television networks began broadcasting 16 hours of predominantly prime-time programming with closed captions produced by the National Captioning Institute, Inc. (NCI).

Closed captioning involves representing the sound track of television programs in subtitles which are telecast as data in the vertical blanking interval and are visible only to those viewers whose sets are equipped with special decoding devices. While in theory closed captions can be provided by any teletext system, only one, currently known as the Line 21 system, is actually in use and delivering captions nationally. At present, 300,000 viewers across the country who use Line 21 TeleCaption® decoding devices enjoy over 40 hours per week of predominantly prime-time network programming. More than 200 major advertisers caption their commercials and support the costs of captioning television specials and series.

Although the closed-caption service began three years ago primarily as a broadcast network service, it has expanded into many other delivery systems -- satellite syndication, videocassette, videodisk, local broadcast and cable.

DEVELOPMENTS IN CABLE

The cable industry's first involvement in closed captioning was the delivery of closed-captioned network programs to subscribers. Since 1982, however, cable support and involvement in the closed-caption service has been active and growing rapidly.

In early 1982 Showtime became the first subscription service to offer its own closed-captioned programming -- the BIZARRE series. Shortly thereafter Showtime added selected movies to its closed-captioned fare. In mid 1982 Colormax Electronic Corporation began production of two closed-caption decoding devices designed specifically for the cable audience -- a combination converter/Line 21 decoder, and a Line 21 decoder module that attaches to a cable converter. Such units and the standard Sears (Sanyo) TeleCaption decoder are being acquired by operators such as Tampa Cable Television and American Cable Systems, whose specific commitments to provide closed-caption decoders were made in their franchise bids.

Cable subscribers can now obtain news and features of special interest to the hearing impaired via the KEYFAX National Teletext Magazine, a service provided cooperatively by NCI and KEYCOM Electronics Publishing. Most recently, Tribune Cable Communications, Inc., has agreed to provide funds to closed caption one movie every month for hearing-impaired subscribers. The first movie captioned under this arrangement is POLTERGEIST, to appear on Showtime in June, 1983. Other MSO's are currently considering similar underwriting arrangements to provide closed-caption services for the benefit of their hearing-impaired subscribers.

While such activities generate enormous good will and demonstrate the cable industry's commitment to serve all facets of its market, they also make good business sense. NCI research indicates that while currently only 38% of all decoder households subscribe to cable television, 82% would subscribe to basic cable services if closed-captioned cable services were available. Under those circumstances, 68% would subscribe to pay cable compared to the 28% who currently do so. Further, of those who do not own a closed-caption decoder, approximately 78% would rent one from a cable company.

CLOSED-CAPTION SYSTEM DEVELOPMENT

The Line 21 system was designed specifically to provide closed captions to the hearing impaired. For this reason, fundamental to its specifications was that it require little investment in effort and hardware by the telecaster, that it be sufficiently rugged to pass unmodified through all television media, and that it be inexpensive for the consumer to access.

Development of the Line 21 closed-captioning system was conducted by the PBS Engineering Department with funds provided by the U.S. Department of Health, Education and Welfare (HEW). This work commenced in 1973 and was largely completed in 1979. The PBS task had three major components, each of which had to be completed successfully before a closed-captioning service could be implemented.

The first task was to evaluate the technique of closed captioning as a meaningful service for the hearing impaired. To measure this, PBS established an experimental closed-captioning capability and conducted controlled testing with the hearing-impaired community during 1974. PBS obtained the cooperation of 12 member stations across the country who demonstrated closed-captioned television programs to the hearing-impaired viewers and had them complete over 1,400 opinion forms. Gallaudet College, the world's foremost educational institution for the hearing impaired, analyzed the completed questionnaires. The major findings were that 90% of the audience said they could not have understood the TV programs shown to them had they not been captioned and 95% said they would purchase special equipment to receive closed captions.

During this same period and on into 1975, PBS was studying the various technical hurdles it faced in developing an approach to closed-captioned television. By November, 1975, sufficient work had been completed for PBS to file a petition with the Federal Communications Commission (FCC) requesting the allocation of Line 21 for the introduction of a closed-captioned service. In December, 1976, the FCC approved such an allocation. With the FCC approval obtained, PBS began fabrication of the caption editing console which enables caption preparation to be completed efficiently, secured agreements from manufacturers to produce the encoder which lays the Line 21 data stream into the vertical interval and the first consumer decoders -- a integrated 19" color television set and the add-on decoder -- which Sears Roebuck agreed to retail. Finally, the question of who would perform the actual captioning service was answered when the non-profit and private National Captioning Institute was incorporated in early 1979.

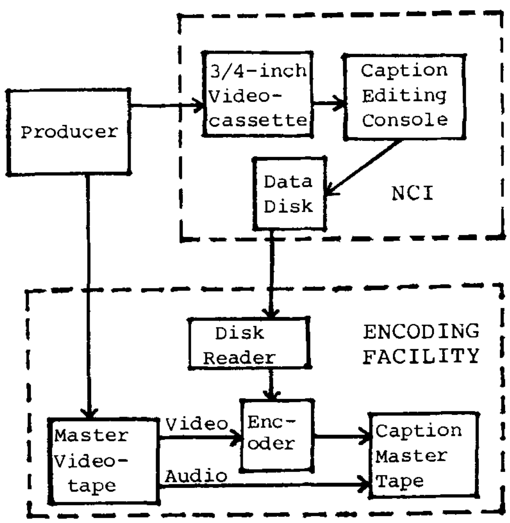
CAPTION CREATION AND ENCODING

NCI creates captions in three different ways, depending upon the nature of the program to be captioned. A recent advance in caption creation technology known as real-time captioning enables virtually every program type to be closed captioned. The three methods employed by NCI to caption, and a method available to local program suppliers, are described below.

Prerecorded Programming. NCI receives a time-coded videocassette dub of the program master and, if available, a script of the program. A caption editor works with the program in short sections, and composes each caption. The editor determines the caption content, its location on the screen, and the times at which it will appear and disappear. All of this data is entered onto an 8" floppy disk via the caption editing console, which has word processing capability to facilitate the process. Once all captions for a program have been prepared and entered, they are played back over video and checked for accuracy and quality.

The captions on disk are transferred to Line 21, Field 1 of the standard NTSC video signal in the encoding process. To encode captions a Simple Encoder, comprised basically of a microprocessor, a time code reader and a floppy disk reader, is utilized. Required inputs are SMPTE time code and program video from the master videotape. The microprocessor synchronizes the serial caption data with the time code and requests additional captions from the disk reader when the encoder memory buffer is near depletion. The caption data is inserted into Line 21 of the video.

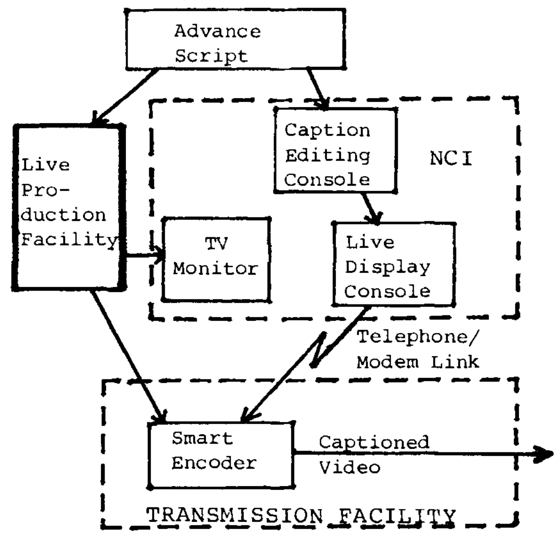
TAPE ENCODING



<u>Prescripted Live Programs</u>. Presidential addresses and other programs which are broadcast live are often accurately prescripted. With the cooperation of the White House or producer, NCI obtains the script in advance of broadcast. Without the benefit of video or audio, the editor must break the text into captions. These captions are entered onto the disk without preset display and erase times. As the live event occurs, the caption editor manually recalls the captions from the disk for display in sync with the audio.

Due to the nature of these programs, encoding must be done "live." The hardware which enables live encoding is a Smart Encoder. This device is resident at the program origination point and is capable of inserting caption data on Line 21 of the video being fed through it. NCI transmits the captions to the Smart Encoder at 1200 baud rate, asynchronously, over standard unconditioned telephone lines.

LIVE ENCODING



<u>Live News and Events</u>. For news and other programs, scripts are not available to NCI in advance of broadcast. Until last year, such programs were uncaptionable. In October, 1982, however, NCI began to employ its real-time captioning system on a daily basis to caption ABC-TV's WORLD NEWS TONIGHT. The system has been employed to caption space shuttle launches and the Academy Awards.

The trick to real-time captioning is that captions must not only be transmitted live, they must be created instantaneously. To accomplish this, NCI has borrowed and modified a technology employed by court reporters to speed the translation of machine shorthand to standard English. Stenographic translation is the computerized translation into real words and names of a stenotypist's machine shorthand "strokes" which are a phonetic representation of what the stenotypist hears.

NCI uses a stenographic translation system developed by Translation Systems, Inc., modified by TSI and NCI and known as InstaText. The heart of InstaText is its dictionary system, which translates the stenotypist's strokes into real English. The main dictionary is called the "universal" dictionary. This contains the many thousands of words in common usage. The universal dictionary is the permanent facet of the dictionary system, though updated and revised from time to time. Next is the "personal" dictionary peculiar to the individual stenotypist which contains special abbreviations, used only by him or her. The third dictionary to which the computer will turn to "look up" a word is the "dope sheet," which contains entries appropriate to a specific task, such as the names and places likely to be mentioned in a given newscast.

In making translations, the computer checks each of these dictionaries and matches the stenographic outline entered on the stenotype machine with the corresponding English word or words. A skilled stenotypist will achieve accurate translation on better than 97% of all entries.

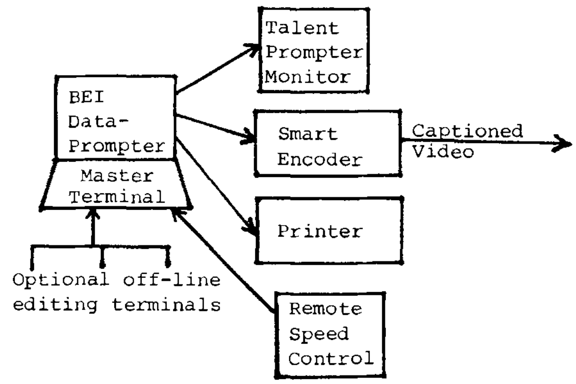
As translation takes place, the text is formatted into captions according to parameters which can be set either by the stenotypist or by an NCI editor operating the main computer keyboard. These parameters can be set in real time so that each line or word can be treated differently, include line length, indentation, upper or upper/lower case, and line justification for left, right, or center display and display rate.

The text must be then transmitted to a display system. In the case of NCI, that system is a Line 21 decoder via the Line 21 Smart Encoder as described above.

Local Programming. Although NCI has and will continue to caption programs for local markets, a very cost-effective system is available to local stations and cablecasters with which to caption programming they produce. This system utilizes a Beston Electronic Data-Prompter and an EEG Smart Encoder. The Data-Prompter is an electronic word processor which has a character-generated output that can be fed directly to a standard prompter monitor. As the text is being presented to the talent, it can also be sent to the Line 21 Smart Encoder, enabling closed captions to be transmitted simultaneously with the program.

KCMO-TV, the CBS affiliate in Kansas City, is currently utilizing this system to provide closed captions for its local newscasts, and many cable systems are showing interest in the system for use with their local access programs.

DATA-PROMPTER CAPTIONING



LINE 21 TRANSMISSION AND RECORDING

Once Line 21 closed captions are inserted into video they require no special accommodation by the broadcaster or cablecaster. All that is required is that video facilities be checked to insure that they are passing Line 21, Field 1 intact. The ease of retransmission is due to the relatively low data rate of the Line 21 signal which makes it very rugged.

The Line 21 waveform conforms to the standard Television Synchronizing Waveform for Color Transmission given in Subpart E, Part 73 of the FCC Rules and Regulations. The composite data signal contained within the active video portion of the line period carries a clock run-in (data synchronizing signal), and a start bit, followed by 16 data bits. The instantaneous data rate is thirty-two times horizontal line scanning frequency ($32F_H$) for a nominal value of 0.5 mb/s. After allowance for the duty cycle of the Line 21 signal, and start bits, an average data transmission rate of 480 bits per second is obtained which translates into 60 characters (7 bit ASCll + 1 parity bit) per second.

Just as Line 21 closed captions pass without difficulty over existing transmission modes -- over-the-air, cable and satellite -- they are recordable in all existing video formats, including 3/4-inch, 1/2-inch (Beta and VHS), and video disk. When programming is transmitted on a 3/4-inch format, however, it is important to note that many 3/4-inch cassette machines do not have framing (field differentiating) servo systems and will randomly lock in the opposite field from a house reference sync. This will usually be the advanced vertical from a time base corrector when it is connected to the playback machine. As a result, Line 21, Field 1 information may flip to Field 2 on either

Line 20 or Line 21. The home decoder must see caption data on Line 21, Field 1 in order to decode and display captions. (The Sony BVU series, or its equivalent, that employs a framing servo does have this problem and can be used with a time base corrector without exhibiting field reversal providing the program was recorded on a machine with a framing servo.)

If a non-framing servo machine is used for playback with no time base correction and the signal that was recorded is at proper IRE levels, then Line 21, Field 1 information recorded on the tape will remain unaltered during playback, allowing captions to be decoded and displayed on the home receiver.

LINE 21 AND TELETEXT

The FCC decision last month to preserve Line 21 for closed captioning came as welcome support to hearing-impaired consumers who have made an investment of over 30 million dollars in home decoding equipment to date. The open-market approach to teletext standards, including the ruling by the Commissioners that cable television systems are not bound by the must-carry rule insofar as broadcast teletext services are concerned, and the adoption of incompatible teletext systems by broadcasters and cablecasters alike, will mean that for the foreseeable future the Line 21 system will remain the only national delivery system for program-related captions.

With the advent of teletext in the United States, NCI recognizes the practicality of making the Line 21 system compatible with the various teletext systems so that hearing-impaired viewers who invest in teletext decoders do not also need Line 21 decoders. Toward that end NCI has been cooperating with World Standard and NABTS teletext equipment manufacturers to develop a black box which can transcode Line 21 captions to either teletext format. Such transcoders will enable captions to pass as usual on Line 21 and to be duplicated and transmitted simultaneously in the appropriate teletext format.

In November of 1982 such transcoding between Line 21 and World Standard teletext was successfully demonstrated in Washington, D.C. In March, 1983, a transcoder was installed at WNET-TV in New York with transcoded captions transmitted by Manhattan Cable. An NABTS transcoder is currently under development in Canada and is expected to be available this fall.

CONCLUSION

The Line 21 system for closed captioning has become widely accepted and utilized in the four years since it made its debut, and its growth continues at an exciting pace. Major support for the system is arising from the cable industry. The creation, transmission and reception of closed captions is reliable, straightforward and proven. For cable operators who wish to provide this valuable service to the hearing impaired, the Line 21-based system is a cost-effective and trouble-free way to do so. NCI has every expectation that the growth of cable television across the nation will lead to increasing access to television for the hearing impaired.

COAXIAL CABLE - THE HOSTILE MEDIUM

Archer S. Taylor
Senior Vice President, Engineering

Malarkey-Taylor Associates, Incorporated
Washington, D.C.

ABSTRACT

The cable television industry has not yet acknowledged the practical impossibility of maintaining the 5 - 30 MHz cable spectrum free of non-Gaussian noise. Modem manufacturers and data network architects either are unaware of the ingressive beasts waiting to ambush innocent upstream data, or naively view them as curable afflictions caused by sloppy design, careless construction, and slothful maintenance. The cost of clean-up can be enormous and never-ending. The time required to locate and repair causes of ingress is likely to be intolerable for services like traffic signal control that demand high reliability. Frequency agile modems, exotic modulation schemes, and sophisticated error detection and correction firmware are expensive, and inefficient. Perhaps the time is ripe for the fully switched, star network topology. Whatever the solution, some means must be devised for upstream transmission that is not so vulnerable to ingress interference.

INTRODUCTION

The cable television industry appears to be on the verge of plunging into the highly competitive interactive telecommunications business. The profit potential seems enormously attractive. We already have communications facilities in place, thanks to the FCC back in 1972 for requiring "two-way capability". All we need, we think, is a few modems, a computer of some sort, and a bit of software, and we are in business.

Not so. I leave it to others to talk about the profit and loss issues, and marketing research, and information banks and software, and storage capacity. I want to talk about the second part of the two-way capability, the part that carries messages upstream. I want to alarm you enough to go out and challenge the system designers and the modem suppliers; but, not enough to scare you away from this exciting new frontier of telecommunications.

THE INGRESS PROBLEM

Do you have, or know anyone who does have, a working upstream network actually providing enhanced services, in addition to home security, producing better than 10^{-8} bit error rate 99.95% (or more) of the time? If you say "yes", then I will ask you to prove it, because I am skeptical. Suppose you use the upstream system for home security alarm responses. Of course, you may incur some legal liability if a house burns or is burglarized, or a panic button fails to bring help. But, really, you may ask, how great is the risk, and who will know, if part of your system is down for the few hours or days required to track down the source of ingress that destroyed the return response? After all, you do have telephone dialers for backup.

On the other hand, suppose you are providing the linkage for a computer controlled traffic system. At 5 o'clock one afternoon, the return signals become unreadable because of severe power line noise interference. After several hours of searching, the trouble is identified, using bridger switches, as caused by a corona discharge in a power substation near the trunk cable. Unfortunately, there was a corroded service drop connector on one feeder near the power substation, and a loose cover plate on a tap on another feeder. While hunting for the problem, traffic became totally snarled at three major rush hour intersections, because of the incorrect signals received by the computer. That would not be so easy to indulge.

Or, suppose you were providing a high-speed, high-density data link service, with packet switching. Down time for maintenance or fault location could mean a disastrous back-up in transmissions causing customers to look for a more reliable communication service.

Why, you may ask, is the upstream transmission band considered so hostile?

First, look at the electromagnetic spectrum in the 5 - 30 MHz band. Seven international broadcasting bands are occupied by high powered transmitters, many of which shift from one band to another as the sky-wave "skip" moves up and down through the band. When conditions are right, signals broadcast from thousands of miles away come in loud and clear on the upstream network. Citizen's Band and amateur Radio transmissions are almost certain to be keyed "on" and "off" within a few yards of the cable somewhere, some with considerable power.

These services occupy about 5.4 MHz, or about 22% of the band. The rest of the spectrum, with a very few exceptions, is allocated to Marine and aeronautical, fixed and mobile services, some of which are also high powered.

You may have a "closed system" that generates less than 20 uv/m at 10 feet at any location; but I assure you that is not tight enough to prevent ingress. It does not help much to claim that the distribution plant has been well and carefully constructed, using RFI connectors and metal gasketed housing covers, all properly torqued down, with shrink tubes covering all splices and connectors, and no kinks or cracks or "ripples" in the cable. The problem is in the service drops, thousands of them, all over the system. As fast as you find one corroded, or broken, or improperly installed F-connector, two more bad ones show up.

The worst of it is that ingress interference may be caused by leakage transfer impedance well below the levels that would show up on the "cuckoo" or even the "Sniffer" monopole.

Even if you spend the time and dedicate considerable manpower to the job, constant vigilance is required to detect and correct the ingress that never stops happening. I am convinced that there is just no practical way to be reasonably confident that the ingress monster will not pop up at any minute and devour unprotected messages.

SOLUTIONS

What to do about it? If you only use the upstream network for status monitoring, ingress is merely an inconvenience. If you use it for home security, you can always back it up with digital dialers, as many operators are now doing. (Parenthetically, one might ask what good is the cable network if half the security subscribers are connected to our friendly telephone competitor's network). If you use it for two-way addressability and pay-per-view, the ingress monster may take a nip at your own bottom line. That could be a problem. But unless you are serious about competing for the interactive telecommunications business, you probably need do little or nothing about ingress, except learn to live with it.

However, if you really want to go after the new revenue potential for transmitting data, the first thing to do is talk to your modem and software suppliers. Don't let them snow you with talk about how well their equipment works at 20 dB carrier-to-noise ratio; they are talking about <u>thermal</u> noise, and that is the least of your problems. Don't worry about bit error rates, either. Practically any equipment will beat 10^{-8} ber under ideal conditions.

You need to find out what kind of error detection and correction protocols are provided in the software. Is either affirmative or negative acknowledgement required before any message can be accepted? Can the modem frequency be shifted to avoid an interfering carrier? If so, is the frequency shift automatically provided in the software? What is the tolerable ratio between the desired carrier level and that of an undesired, interfering discrete carrier? How much impulsive noise (from auto ignition or electrical machinery) can be tolerated before the information is lost?

I hope I am wrong, but I suspect you will get distressing answers. They will tell you that such sophisticated protocols are too expensive and unnecessary; they occupy too much bandwidth, or waste too much time. They will tell you how successfully their simple parity check polling system works, here, there, and the other place. They may even try to tell you that if you build your system "right", and maintain it "properly", you can eliminate ingress interference.

Actually, sophisticated protocols are expensive; they are less efficient because they occupy more bandwidth; and it does take time to acknowledge message receipt and correct errors. One way out might be to transmit the data at slow speed and narrow bandwidth; but what advantage would narrow band transmissions on cable have over ordinary telephone lines, except for security alarms, pay per view, status monitoring, and other internal uses? New revenues are most likely to be realized by offering medium-and high-speed data transmission services, not narrow band.

The most successful commercial data transmission services on cable TV today are provided on special cable networks mostly separate from the subscriber network. The institutional network (I-Net), if properly used, could be a good solution to the problem in some cases. However, users should not be connected with braided cable and F-connectors, and user terminals should be well-shielded and free of direct pickup ingress. Data channels should be allocated to portions of the spectrum with a limited number of identifiable interfering carriers; the TV channels, for example, with one main carrier and two attenuated subcarriers are far more suitable than the 5-30 MHz band.

The I-Net does not, however, solve the problem of providing enhanced services to cable TV subscribers. Several years ago, Jerrold put forth a system to convert the 5-30 MHz carriers at the bridger to higher frequencies for transmission to the headend on a second cable, independent of the subscriber trunk. Perhaps this idea should be resurrected, though I believe it should be modified so that each bridger, or perhaps pair of bridgers, would convert to a different channel. I suspect this would be a better way to use the 500 MHz bandwidth capacity.

The code operated bridger switch (COS) is a successful technique for disconnecting most sources of noise and interference during the upstream transmission. However, communication with a particular terminal would only be possible for the brief interval during which the feeder was connected. Thus, all communication services would have to be synchronized to the switching control cycle. This would be ideal for polling protocols, but would impose an intolerable restriction on other communications.

THE STAR NETWORK

A much better long-range solution, in my judgment, at least for new systems, is the star distribution network topology. To old-timers, this is simply a fancy name for the "switched system" promoted 10 or 15 years ago in Britain by Rediffusion, Ltd. as "Dial-a-Program", and in the U.S. by Ameco as "Discade". The C-COR and Texscan off-premises converters, and the Times Fiber Mini-Hub could also be called star networks, using remotely switched converters instead of baseband or R.F. switches.

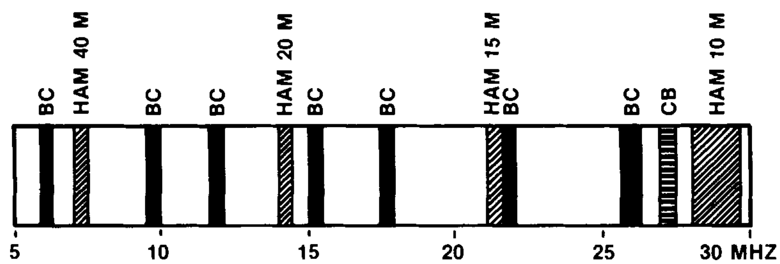
The star network has many advantages (and a few disadvantages) for distribution of television programming to subscribers. But the decisive advantage for interactive message service is that individual subscriber data channels can be switched at the hub to protected trunk channels. The tree-and-branch network is basically a party-line, always open to the noise and ingress picked up by many subscriber service drops. The star configuration, with hub switching, can provide private line protection for individual messages. Concentrators at the star hubs would convert low speed data on the subscriber service drop to high speed data for time division multiplexing on the trunk. Depending on the traffic load, therefore, each data channel on the trunk could serve many subscribers.

To the best of my knowledge, none of the presently available off-premises equipment includes data switching facilities. Digital switching hardware is available in the telephone industry, and could be readily adapted to cable distribution in the star configuration.

The Times Fiber Mini-Hub, using optical fibers for the service drop, is potentially a major advance over off-premises systems using coaxial drops. The fiber is much more difficult to tap illegally; it is almost immune to ingress interference; and its losses are low enough to permit much longer drops.

The most often cited disadvantage of the star (or off-premises converter) network is the psychological hazard of marketing a service which, like telephone service, requires a separate drop for each fully independent outlet. We do have an advantage over the telephone facility in that it is technically feasible to multiplex two, and perhaps more,

UPSTREAM CABLE SPECTRUM



White Spaces assigned to Marine and Aeronautical Fixed and Mobile

separate channels on either coaxial or fiber drops. In most places, for example, Channels 2, 3, or 4 are available for the first service outlet; Channels 5 or 6 would be equally available for a second outlet.

Until optical splitters are available at reasonable loss and manageable price, the Times Fiber system requires two fibers, one upstream, the other downstream. The upstream fiber is quite capable of carrying not only the remote channel selection signals but digital messages as well.

CONCLUSION

After you have worked night and day for months, and spent hundreds of thousands of dollars trying to make your system tight, free from ingress - or reasonably so - I think you will understand what I mean by the "hostile medium".

In my opinion, if we intend to offer "two-way interactive" data services in competition with MCI, Bell, AT&T, and others, we simply cannot fool around with ingress at 5-30 MHz. NASA is still in communication with Pioneer 10 as it passes the planet Neptune, notwithstanding nearly three billion miles of hostile outer space; so far, in fact, that it takes 4 hours for a message to make the trip, each way. Protocols and technology are now available for successful transmission through the interference in our hostile coaxial cables, and the costs, although higher, are probably not prohibitive. Moreover, several more forgiving configurations of the network topology are also available that avoid the accumulation of ingress. Maybe we need both; but we need something fast.

We can no longer afford to play with rubber band airplanes while our competition is building jets.

Malarkey-Taylor Associates
1301 Pennsylvania Avenue, N.W. Suite 200
Washington, D.C. 20004

COAXIAL CONNECTOR PERFORMANCE

John Mattis

RAYCHEM CORPORATION, TELECOMMUNICATIONS DIVISION

ABSTRACT

This paper presents a series of test methods that were used to evaluate the mechanical performance of .50 inch diameter feed through coaxial connectors. The testing revealed that correctly installed connectors are as strong as the cable outer sheath, but that connectors are craft sensitive to install. Incorrect installation can lead to mechanical and hence, electrical failure.

INTRODUCTION

There have been many technical papers and articles published which address the problems of signal leakage or radiation ingress in the cable system. The cables themselves are virtually radiation proof. Connectors, amplifier housings, and taps are the principal cause of cable system radiation. When we asked the cable system operators what their problems were, the connector, one of the least expensive components, was then pointed out as a major problem. Since we could find no published industry standards on how to evaluate the mechnical integrity of the connector, we developed a series of tests to simulate the expected environmental conditions a connector could see.

As the cable system should be designed for a lifetime in excess of 20 years, test methods are used which monitor the effect of accelerated product aging. The mechnical integrity of the connection affects the connector's electrical performance and shielding effectiveness in a negative manner if it is not capable of withstanding the environmental loads. The mechnical test program was designed to evaluate a connector's strength.

CRAFT SENSITIVITY

To further the program and gain added insight to the reliability of Raychem and competitive connectors, a craft sensitivity test program was performed. The test program included Raychem technicians with good mechnical skills and CATV craft installers from local MSO's. All individuals received a demonstration of how the connectors were to be assembled in accordance with the manufacturer's instructions. The completed samples were, with the use of an Instron tensile tester, pulled in the axial direction to measure the load until failure or pullout occured.

In all cases cable jacket stripping was performed by Raychem laboratory personnel to ensure that no cable sheath nicking damage would occur, thus voiding the test sample. The participants were permitted to use whatever tools they thought were appropriate.

All connectors were assembled in an aerial mode with a tap box attached to a strand, supported between two poles. An enclosed platform simulated a bucket truck.

The .50 inch feed through connectors chosen for this program were a new improved design and two of the most popular mechanical connectors used by the industry.

The new Raychem ThermoCrimp connector system consists of an Alodine-600 coated aluminum connector body and a molded high recovery force polymer (HRFP) crimp ring coated with a temperature indicating paint. The connector is shown in Figure 1 before installation, before heating and after the installation is completed.

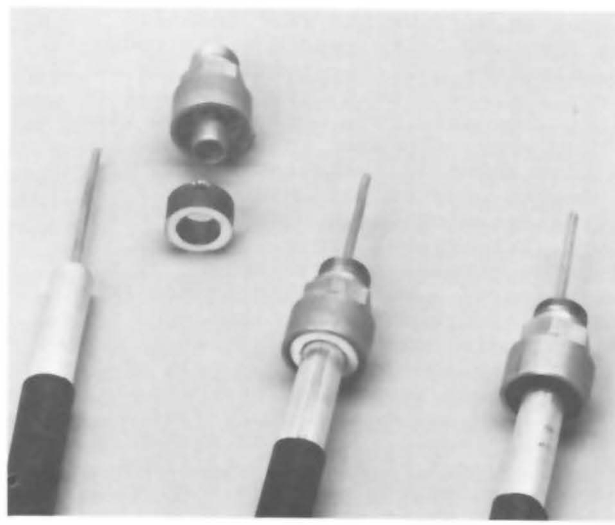


Figure 1

A properly installed connector would, in all cases, result in breakage of the cable outer sheath. An improperly installed connector would slip from the cable sheath as the load was applied.

The results of testing three different types of connectors installed by ten individuals are shown in the following tables. Failure is defined as the connector slipping from the end of the cable.

Raychem Personnel

BRAND	NUMBER OF PEOPLE	NUMBER OF PIECES	FAIL	PERCENT FAIL
Raychem	7	16	0	0
B	7	16	6	38
C	7	16	6	38

CATV Personnel

BRAND	NUMBER OF PEOPLE	NUMBER OF PIECES	FAIL	PERCENT FAIL
Raychem	3	7	0	0
B	3	7	1	15
C	3	7	1	15

The Raychem connector is significantly less craft sensitive to install. Out of a total of 23 connectors that were installed in this test program by all ten individuals, none failed.

When investigating why improper installation occurs, it was found to be due to the basic design of the mechanical connectors. That is, they employ inclined planes and threads to force a split clamping ring down against the outer conductor. This in turn is supported by the integral mandrel. The installer judges the quality of installation by feel, as to the correct installation torque. It is well known that the use of torque to indicate a good installation is poor primarily due to friction between the threads and mating surfaces. Many industries where correct preload of threaded connections is critical for proper performance utilize skilled craftsmen, friction reducing means and sophisticated torque measurement equipment to indicate proper installation.

Another problem observed with the mechnical connectors was the tendency of the expansion loop to twist as the final tightening was performed. Eliminating this tendency is difficult and awkward.

MECHNICAL TESTING

The Coaxial Connector System testing specification that was chosen to evaluate connector performance is based upon similar specifications that are used by both the telephone and electrical utility industries to predict their product lifetimes.

It is well known that the prime load carrying member of a coaxial cable is the outer conductor. Axially loading a sample of the outer conductor of a typical .50 inch diameter coaxial cable resulted in failure at approximately 490 pounds, as shown in Figure 2.

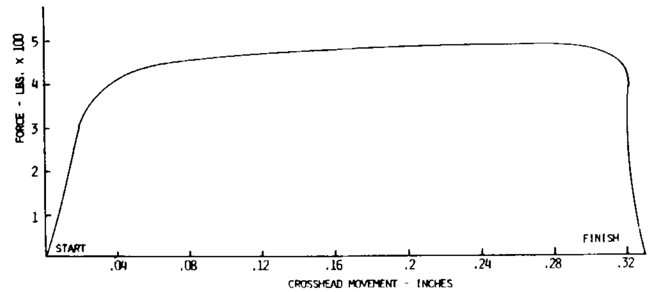


FIGURE 2

Additionally, the .110 inch diameter inner conductor will fail at approximately 190 pounds. In fact, due to the damage caused by tightening the tap box set screw, it will fail at a load of approximately 140 pounds. Perhaps of more importance is the reduction in elongation from 6.0 percent down to 2.4 percent caused by the set screw acting as a stress riser, as shown in Figure 3.

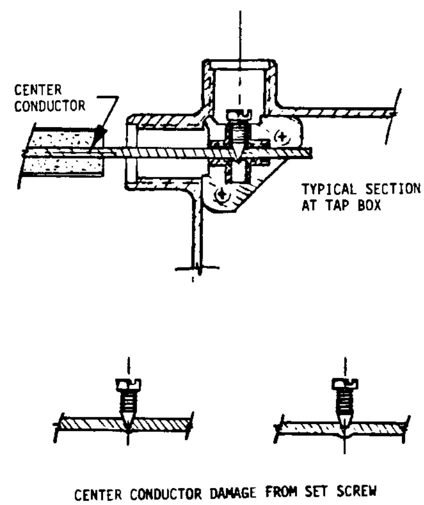


FIGURE 3

This means that with an improperly installed connector, as shown in Figure 4, in which the outer conductor is not tightly gripped, any small amount of axial movement can result in breakage of the center conductor.

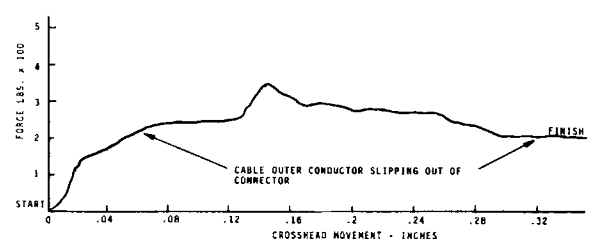


FIGURE 4

The assumption was made, therefore, that all of the environmentally induced loads must be carried by the cable outer conductor. The environmental loads imposed on the coaxial cable system are tension caused by temperature changes and ice loading, along with vibration effects caused by the wind. These loads may act alone or in combination with each other.

For a typical .50 inch diameter coaxial cable most manufacturers recommend a maximum pulling force of 200 pounds to prevent damage to the cable during installation. Our preliminary testing using mechnical connectors showed that for improperly installed connectors slippage of the outer conductor from the connector was initiated at loads as low as 200 pounds. After some movement, the load would approach 400 pounds prior to the cable pulling out of the connector. The amount of slippage observed would easily cause breakage of the center conductor.

Our testing also shows that in every case a properly installed connector would result in failure of the cable sheath when loaded in tension.

For the .50 inch diameter coaxial cable that was used, the test load was derived as follows:

The outer sheath has a tensile yield strength of F_{ty} = 10,000 psi

The cross sectional area of a typical .50 inch outside diameter cable with a .025 inch thick wall = $0.0373 in^2$

The axial load carrying capability at yield is given by the equation,

$$P = F_{ty} \times A = 373 \text{ pounds} \qquad (1)$$

Initial testing with a sustained load of this magnitude indicated that failure of the outer sheath would occur if the load was maintained. Good engineering judgement suggested a reduction of the load at yield by 20 percent would be appropriate to serve as the test load, or

$$P_{test} = .8 \times 373 = 300 \text{ pounds.} \qquad (2)$$

Since it is possible to install a coaxial connector in a manner that will allow the passing of the axial load requirement, but still allow the connector to rotate with respect to the cable, an installed connector torsion test was devised. Again, using a .50 inch diameter cable, samples were tested in an Instron to determine the amount of torque required to yield the cable outer conductor. This was found to be 58 inch-pounds.

The test recommended is to apply a torsional load of 50 inch-pounds (a small amount below the yield point) before and after the environmental cycling test. The environmental cycling test employed is similar to ones used by utility companies to evaluate component materials and can predict life times in excess of thirty years, see Figure 5.

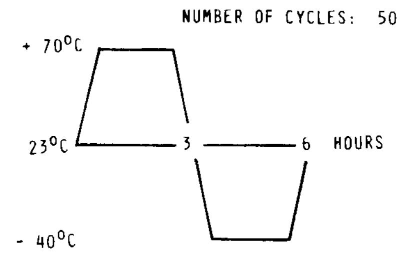


FIGURE 5

Other tests were axial shock and bending to simulate in an accelerated manner the effects of wind loading.

The following is the final proposed test program for .50 inch diameter coaxial cable. The necessary test loads for any other sizes can be easily determined.

<u>Axial Tension Test</u>

<u>Axial Tension Test</u> was performed as follows: Cable samples prepared with connectors on each end shall be loaded in tension with the force specified below for a period of 6 hours at -40°C.

CABLE SIZE	AXIAL LOAD
500	300 + 5 Pounds

<u>Thermal Aging</u>

<u>Thermal Aging</u> was conducted as follows: Cable samples prepared with connectors on each end shall be loaded in tension with the force specified below. The samples shall be placed in an air circulating oven at 70°C with an air velocity of 30 to 60 meters per minute for a period of 168 hours.

CABLE SIZE	AXIAL LOAD
500	300 + 5 Pounds

<u>Axial Shock Loading</u>

<u>Axial Shock Loading</u> testing was performed as follows: Cable samples prepared with connectors on each end shall have the axial impulse load shown below, applied at a rate of one cycle per second for a period of 6 hours at both -40 and +70°C.

CABLE SIZE	AXIAL LOAD
500	300 + 5 Pounds

<u>Environmental Cycling</u>

<u>Environmental Cycling</u> was performed as follows: Cable samples prepared with connectors on each end shall be loaded in tension with the axial loads shown below and environmentally cycled. Cycling consists of 50 continuous cycles of -40°C, +70°C and -40°C. The cycle shall run 6 hours. Each cycle shall consist of 2 hours at

+70°C and -40°C. The transition time between the high and low temperature limit is 1 hour.

CABLE SIZE	AXIAL LOAD
500	300 + 5 Pounds

Torsion Testing

Torsion Testing the cable samples from the environmental cycling test shall be subjected to the torque values shown below at 70°C before and after the environmental cycling.

CABLE SIZE	TORSION LOAD
500	50 + 1 Inch-Pounds

Bend Testing

Bend Testing was performed with the cable specimens prepared with connectors on both ends. They shall have a cyclic bending force appled to the cable. The test consists of multiplanar bending achieved by fixing one end of the specimen and rotating the other end around the cable axis while simultaneously applying the axial load shown below. The test duration is 4 hours at a loading rate of one cycle per second. One end of nine inch cable specimen is displaced from the cable axis by 0.10 inches.

CABLE SIZE	AXIAL LOAD
500	300 $\pm$ 5 Pounds

Flexure Testing

Flexure Testing of the cable samples was performed as follows: A five foot long cable sample is prepared by forming two smooth bends into the cable to make an eight inch displacement in the cable axis. The sample with connectors on each end is then tested to failure by fixing one connector and displacing the other connector 1.5 inches in the axial direction.

Water Seal

Water Seal testing was performed in order to evaluate the water seal between the cable and the connector. Samples of installed connectors were subjected to a three foot external waterhead and monitored for leakage.

Pressure Seal

Pressure Seal testing was performed as follows: Samples of installed connectors are pressurized with air to a pressure of 60 psi. The sample passes if it retains pressure for 4 hours. Pressure loss is detected by water submersion and the presence of bubbles.

SAMPLE PREPARATION

Based on the craft sensitivity testing and reports from the cable system operators on cables pulling out of connectors, we prepared one half of all the cable samples with controlled mis-installed connectors, as well as correctly installed connectors. The correct and incorrect installation of each connector was performed as follows. For each test we used equal numbers of correctly and incorrectly installed connectors.

Raychem ThermoCrimp

The correct installation of the Raychem ThermoCrimp is determined by complete conversion of the thermochromic paint from white to black. For the incorrect installation we only converted one half the paint.

Connector B

Connector B's correct installation of torque was a minimum of 25 foot-pounds of torque. The incorrect installation was 11 foot-pounds of torque.

Connector C

Connector C's correct installation was a minimum of 14 foot-pounds of torque. The incorrect installation was 8 foot-pounds.

TEST RESULTS

Axial Tension	Pass	Fail
Raychem ThermoCrimp	16	0
Connector B	14	0
Connector C	11	1

Thermal Aging	Pass	Fail
Raychem ThermoCrimp	16	0
Connector B	14	0
Connector C	11	1

Axial Shock Loading	Pass	Fail
Raychem ThermoCrimp	24	0
Connector B	24	0
Connector C	20	4

Environmental Cycling	Pass	Fail
Raychem ThermoCrimp	32	0
Connector B	24	0
Connector C	18	6

Torsion Test	Pass	Fail
Raychem ThermoCrimp	32	0
Connector B	24	0
Connector C	18	6

Bending Test	Pass	Fail
Raychem ThermoCrimp	16	0
Connector B	16	0
Connector C	16	0

Flexure Test	Pass	Fail
Raychem ThermoCrimp	12	0
Connector B	12	0
Connector C	12	0

Water Seal Test	Pass	Fail
Raychem ThermoCrimp	12	0
Connector B	12	0
Connector C	12	0

Pressure Seal	Pass	Fail
Raychem ThermoCrimp	10	0
Connector B	10	0
Connector C	10	0

CONCLUSIONS

1. Any coaxial connector that utilizes chucks, inclined planes, and screw threads to properly clamp the coaxial cable appears to be more craft sensitive to install than the ThermoCrimp connector.

2. The flexure test did not result in any failure adjacent to the connector, but did cause cable outer sheath breakage in the bends. These cracks, which for jacketed cable cannot be seen, can easily cause signal ingress or egress problems.

3. The center conductor gripping device used in amplifier housings and passive devices seriously weakens the center conductor.

4. Two of the test parameters, craft sensitivity and environmental cycling, appear to be the most descriminating as a means of evaluating connector mechanical performance.

5. We also found out that any connector should not be reused or used as a union. The gripping mechanism in the mechanical connectors, if correctly installed, put circumferencial scratches in the cable's outer conductor. The result is, if disconnected and then reinstalled, a weakening of the cable axial load carrying capability due to the scratches.

REFERENCES

1 E. Winston, "Stress Analysis of CATV Aluminum-Sheathed Cables Lashed to Hanging Steel Strand", IEEE Transactions on Cable Television, Volume CATV-1, No. 1, October 1976.

2 Brad Kellar, "Standardized Return Loss Measurement of Cable Television Distribution Connectors", 32nd Annual NCTA Convention Technical Papers, 1983.

COMPUTER ASSISTED RF PERFORMANCE TESTING

Jack Koscinski
Director of Product Engineering

Dan Earley
Staff Engineer

Warner Amex Cable Communications Inc
Plainfield, NJ

ABSTRACT

Evaluating the RF performance parameters of CATV products can be quite cumbersome. Some of the major performance parameters are: gain, flatness, return loss, noise figure and distortions. Certain distortion tests such as composite triple beat, cross-mod and second order are especially time consuming and require a high level of operator skill to interpret the desired data accurately.

The introduction of RF computer controlled test equipment has made it possible to perform all of the above RF performance tests automatically under the supervision of a controller. The test programs (software) can be written in a high level language such as "BASIC", thus enabling expedient program development.

This paper describes the equipment requirements and test methodology used in implementing such a test station at Warner Amex to facilitate RF product evlauations.

INTRODUCTION

Computer assisted RF proof of performance testing capability has been available for some time now. The advent of the Hp 8568A Spectrum Analyzer in 1978 was instrumental in providing this capability. I. Switzer described the merits of this spectrum analyzer in a previous NCTA paper "The Spectrum Analyzer As A Computerized Proof of Performance Machine" (1).

Magnavox's Mobile Training Center has incorporated an impressive computer controlled RF proof of performance test system utilizing the Hp 8568A Spectrum Analyzer, Matrix ASX-16 Signal Generator, and the Matrix AR-12 Distortion Receiver. This RF test system is controlled by an Hp Computer and performs system sweep response, carrier/noise, and composite triple beat measurements.

Warner Amex has recently established a Product Engineering department whose function is primarily concerned with product evaluations of all CATV products. To support this activity Warner has implemented a product evaluation facility that is equipped to perform comprehensive performance evaluations on most of the CATV products used in its systems.

Taking advantage of the availability of computer controlled test equipment, Warner Amex has developed an automated RF test system that performs many of the RF performance tests. Among the tests presently automated are gain, response, composite triple beat, cross-mod, second order and noise figure.

The objective of this paper is to describe this RF test system implementation and review some of the testing considerations that led to the selection of the specific equipment in this set-up.

RF PERFORMANCE TESTS: SELECTION AND CONSIDERATIONS

The initial step in the development of the RF test system was to establish the main RF testing objectives. Which RF tests should be performed? What degree of automation should be implemented?

The main application of this RF test system is to perform new product acceptance tests on CATV products. Amplifiers, set-top converters and CATV passives such as multi-taps, traps, etc. are the principle products to be evaluated.

A synopsis of the major RF tests and associated testing considerations are presented below. Conventional test problems are identified to highlight the areas that an automated system may alleviate.

Gain/Response

Gain and response measurements are key tests for most CATV products. These measurements are performed using conventional sweep techniques. An important consideration in gain/response testing is to anticipate the requirement for testing a converter type product. Converters translate the input frequencies to different output frequencies and thus require a broadband detector to accurately display the response. Unfortunately, dynamic range is sacrificed in using a broadband detector. A technique that provides excellent dynamic range utilizes a tracking generator and spectrum analyzer but this equipment cannot test converters because the generator and spectrum analyzer (receiver) track each other at the same frequency.

A solution is to utilize a signal generator to sweep thru the input frequency range and store the output response on a spectrum analyzer by using the storage mode. This technique provides good dynamic range and frequency translation compatibility.

Return Loss

Return loss measurements typically are performed using a bridge and reference termination. The 0dB return loss reference is established by applying a short or open to the test port on the bridge. Then the unit under test is connected and the difference between the reference and test response is the return loss.

Unfortunately the reference response is not normally flat and therefore interpretation of the return loss is tedious. An equipment/system feature that provides an (A-B) mode can cancel out the reference ripple and thus provide a flat reference for measurement ease and accuracy. This feature could be performed by the equipment directly or a controller can provide this mathemathical operation.

Composite Triple Beat (CTB)

Distortion measurements are cumbersome tests to perform manually. There are numerous channels and signal level combinations that could be tested. Automation of composite triple beat testing is one of the principle justifications for implementing a computer assisted RF test system.

A popular approach for measuring CTB utilizes a multi-channel signal generator and spectrum analyzer. The spectrum analyzer may also generate distortion and thus a filter must be used to eliminate all channels except the desired from reaching the spectrum analyzer full strength.

An alternative approach to CTB measurement utilizes the Matrix AR-12 Distortion Receiver. The AR-12 consists of a tuned receiver and AM detector that detects CTB components within $\pm$ 17.5KHz of the carrier.

A precaution should be understood when testing CATV converters. Converters commonly have some residual FM on the output frequency. This is especially true of converters that use LC oscillators. This residual FM may be converted to AM in the highly selective input filter of the AR-12. The CTB detector would interpret any AM within its bandwidth as a CTB component. A solution consists of bypassing the AR-12 filter and employing an external single channel SAW filter.

Cross-Modulation

Cross-modulation tests have been of less interest with the advent of equipment operating with greater than 36 channels. Nevertheless, it should be anticipated in a comprehensive test system. Several products such as CATV converters have been recognized to be distortion limited by cross-mod rather than CTB. This is probably due to the second mixer providing significant contribution to the total distortion.

A common error is sometimes made in cross-mod measurements. The cross-modulation is measured with a spectrum analyzer directly by comparing a 100% modulated signal (reference) to the resultant modulation (distortion) when the reference modulation is removed.

The spectrum analyzer display should not be used directly for the measurement because the display consists of all cross-modulation components (AM and PM). Since the TV receiver is an AM detector, only the AM components of cross-mod should be accounted for.

There are two popular approaches to perform this type of cross-mod measurement. First, the spectrum analyzer can be used as an AM receiver with the AM detected signal output supplied to a wave analyzer. A comparison can then be made between 100% reference modulation and resultant cross-mod. The second approach utilizes the Matrix AR-12 Distortion Receiver where the Matrix AR-12 incorporates a commutative filter processor that provides measurement capability of greater than 100dB.

Carrier/Noise

Carrier to noise measurements are important on their own but they can also be used to provide noise figure measurements. A reference calibrated noise source and a power measuring instrument such as a spectrum analyzer are required for the noise figure tests.

DESCRIPTION OF SYSTEM EQUIPMENT

Once the RF test objectives and considerations were identified an RF system design plan was developed. Most of the equipment required was off the shelf except for the Matrix Signal Generator and Distortion Receiver.

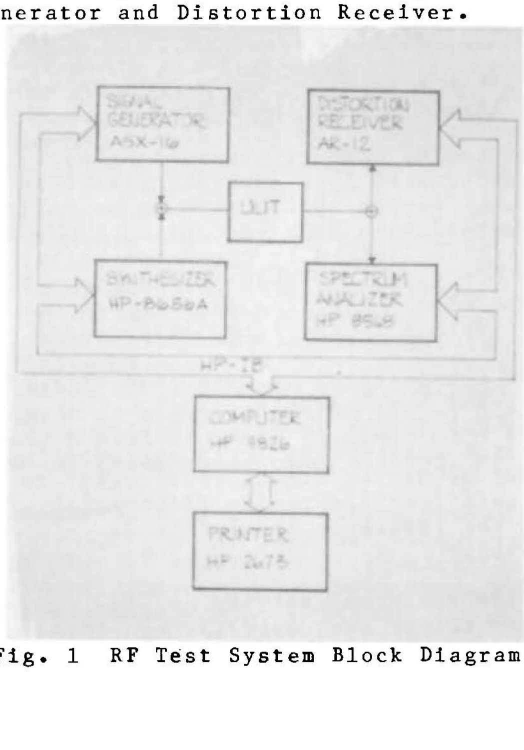


Fig. 1 RF Test System Block Diagram

Although Matrix has provided computer controlled versions of this equipment to several customers each of them tends to be somewhat custom. Warner developed a specification to define the required features and functions necessary for the RF product evaluation application.

The computer assisted RF test system block diagram and equipment are shown in Fig. 1 and 2. The major components are:

- Computer Hp 9826
- Signal Generator : Hp 8656 A
- Multi Channel : ASX-16
  Signal Generator
- Distortion Receiver : AR-12
- Spectrum Analyzer : Hp 8568
- Printer Hp 2673

Communications to and from each piece of equipment is supervised by the Hp 9826 computer controller using the HP-IB interface bus. A functional description for each of the main equipment in this system is discussed below

Computer; Hp 9826

The Hp 9826 (Fig. 3) is a powerful tool for measurement automation. It is friendly, easy to use and offers uncomplicated program development. The Hp 9826 is an integrated package with built in CRT and a single floppy disk. A choice of three programming languages are available. There's Hp enhanced

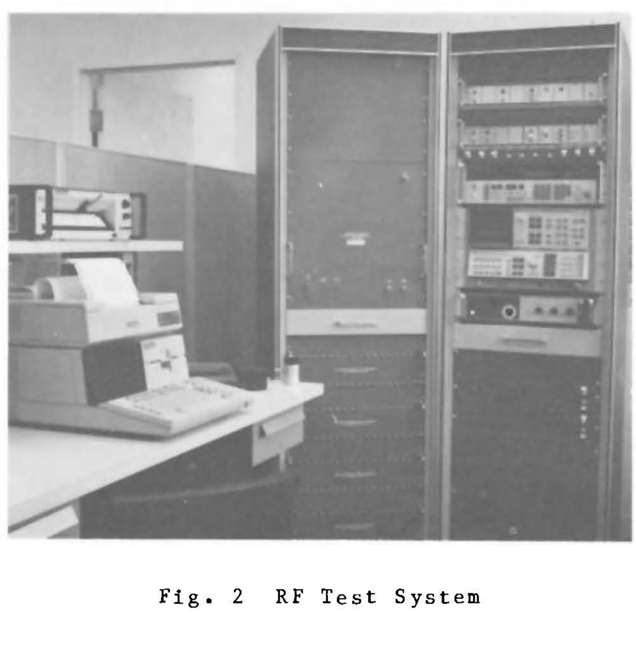


Fig. 2 RF Test System

Fig 3. Hp 9826 System Controller

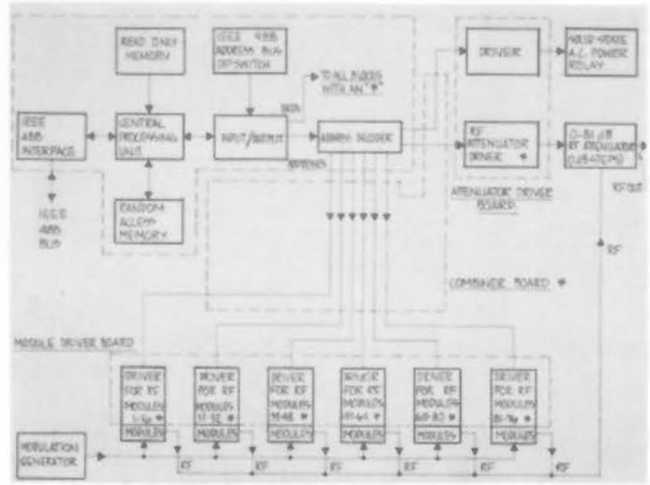


Fig. 4 ASX-16 Signal Generator

Basic, HPL, and Pascal so one can match needs and programming experience with the right language. A standard feature is the HP-IB interface card. The HP-IB is a well defined general purpose digital interface system which simplifies the design and integration of instruments and computers into systems. All of the equipment in this test system utilize the HP-IB interface for communications with the controller.

Signal Generator: Matrix ASX-16

The ASX-16 is a multiple frequency signal generator which can be equipped with up to (100) crystal controlled modules. Each module can be individually turned on or off, modulated with a 15.75 KHz signal, set for CW (no modulation), and output leveled over a $\pm$ 5dB range. A final RF output attenuator may vary the combined channels over a range of 0 to 81dB in 1dB steps. There are 64 channels in this test system which span the range from 5 thru 440 MHz. Additional channels may be retrofitted at a later time if required.

Output levels up to 50 dBmV are available with all harmonics and intermodulation products below 100dB. A block diagram of the ASX-16 is shown in Fig. 4.

Distortion Receiver: Matrix AR-12

The Matrix Distortion Receiver is a multi-purpose device designed to perform cross-modulation and composite triple beat measurements automatically for any channel in the 5 to 440MHz bandwidth (64 channels). Additional channels above 440MHz are available from the manufacturer and may be retrofitted into the basic equipment if required at a later time.

The AR-12 receiver (Fig. 5) contains two detectors. For cross-modulation measurements a commutative filter processor is employed which provides a measurement range greater than 100dB.

Commutative filtering provides detection results comparable to synchronous detection without the accurate phase tracking requirement between the reference and test signals. Phase tracking can be a problem when performing distortion tests of an amplifier cascade with 16 to 20 amplifiers.

In the commutative filter approach a distortion generator detects the modulation components and uses this resultant signal to synchronize a narrow band commutative filter and peak detector.

Composite triple beat measurements are made using a composite triple beat processor. The processor bandwidth is 17.5 KHz and the detector measures the RMS value of the distortion. A high

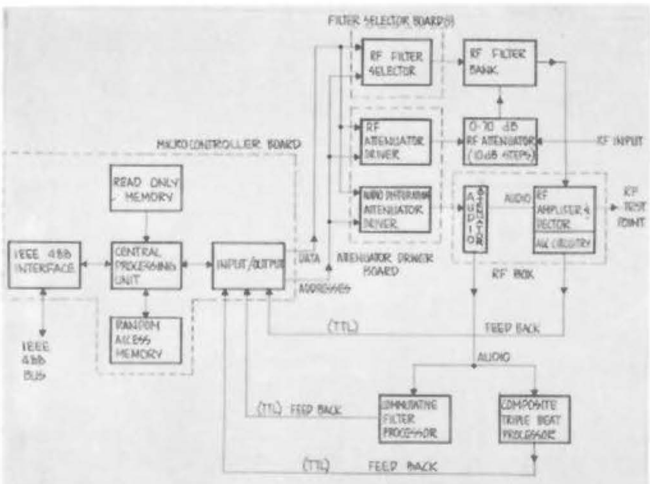


Fig 5. AR-12 Distortion Receiver

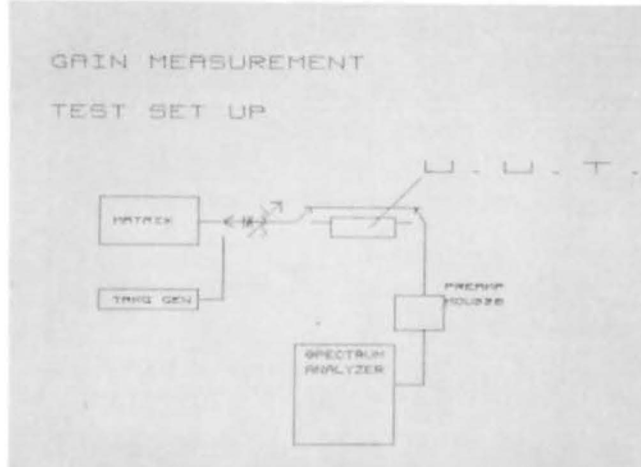


Fig. 6 Gain Test Block Diagram

pass filter near the low end of the band can be added if hum problems are masking the real CTB distortions.

Spectrum Analyzer; Hp-8568

The Hp 8568 Spectrum Analyzer provides unprecedented precision, range, and capability in RF spectrum analysis. All the essential front

panel control settings may be programmed via the HP-IB. Programming codes are powerful, very user friendly and provide for interactivity with the operator.

One of the most powerful features of the analyzer is the marker functions. A marker can be tuned to a particular signal with the amplitude and frequency automatically read out on the CRT screen. Additionally, a peak search can be activated that quickly places the marker on the peak signal of the display. Finally a delta marker mode is available that supplies two independent markers. The frequency and amplitude difference of the two markers is read-out on the CRT screen and may also be read-out onto the HP-IB bus.

User messages can be printed onto the spectrum analyzer screen from the computer thus providing titles for the data or prompts to the operator to perform a certain task. Equipment test set-ups may also be drawn on the CRT screen (Fig. 6).

Another very useful feature of the Hp 8568 is the trace storage (max hold) function. The largest amplitude occuring at each of 1001 horizontal points across the CRT screen can be stored and with a simple program this data can be dumped onto a printer. This feature is handy to use in conjunction with manual testing in that it provides a convenient hard copy without requiring photographs. Fig. 7 and 8 demonstrate this capability.

The Hp 8568 has proven to be a precious and valuable measurement resource. Even without using the bus programmability feature of the equipment, the performance and user features may justify the expense of this equipment over other non programmable analyzers. The front panel of the Hp 8568 is indeed a friendly face.

The performance of the Hp 8568 is unparalled. Some of the key performance specifications are listed below.

- 100 Hz to 1500 MHz Frequency Measurement Range
- 10 Hz to 3MHz Resolution Bandwidth in 1, 3, 10 sequence
- Noise Sidebands 80dB down 300Hz away (10 Hz bandwidth)
- 85dB Spurious Free Dynamic Range
- -85 dBmV to + 80 dBmV Amplitude Measurement Range

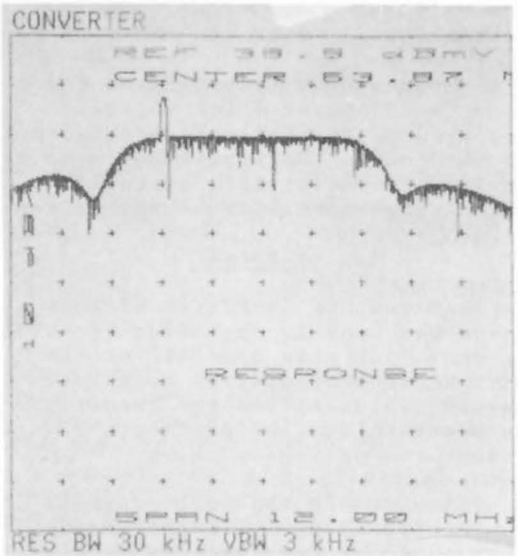


Fig. 7 Response Plot

- Counter Frequency Accuracy (1×10^{-9}/Day)
- Amplitude Accuracy ($\pm$ 1.5 dB)

SOFTWARE ASPECTS

The predecessor of the Hp 9826 computer was the Hp 9825 which utilized the HPL programming language. This language was quite efficient in producing fast test programs but was not as user friendly as "Basic". With the advent of the Hp 9826 computer, the "Basic" language is now available for developing effective computer test programs with the simplicity of a high level language.

Test programs are written in modular form which can be called out by a control program as required. All the test programs utilize a menu format and provide prompts and if, required, an explanation of how to set-up the equipment connections.

Operator interactivity is utilized whenever practical to avoid undue complication of hardware or software. For example, there may be a requirement to turn a unit off that is not normally bus controllable. The test program would pause and instruct the operator to perform this operation manually and then proceed with the measurement. Many items such as this arise once an automated system is implemented.

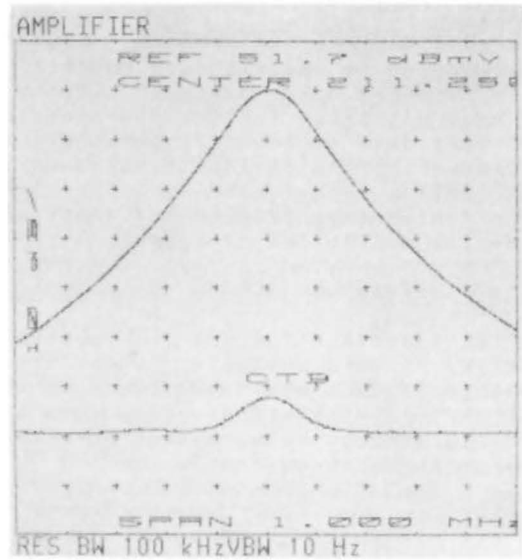


Fig. 8 CTB Distortion

Individual commands to the respective equipment are very simple and straight forward. The protocol consists only of an address (for the particular equipment) and a command (for the particular function).

BENEFITS OF THE COMPUTER ASSISTED RF TEST SYSTEM

This computer assisted RF test system has provided many advantages over conventional manual test methods.

Accuracy And Precision

Tests are performed accurately with the computer tirelessly providing the set-up conditions and taking the data. Precision is enhanced by the computer taking data with more significant figures. Computations may be performed in the computer prior to outputing the final answer thus eliminating data transfer errors.

Repeatability

Tests conducted using the computer enforce consistancy. The computer performs tests in the same sequence using the same set-up conditions as prescribed in the control program.

Operator Skill Level

Skill level of operator can be lowered once the test programs have been developed and debugged. Although test knowledge is important it is not as essential since the computer controls most of the testing. Operator interaction is desirable in certain circumstances. For example, a test program may pause and ask the operator to input data or identify the test parameter. Eliminating the operator interaction may require an extremely complicated test program and additional computer controlled equipment.

Data Analysis

An important feature of computer testing is data analysis. When large amounts of data are taken the computer can perform statistical operations to provide summary results such as worst case, range, average etc.

Speed

Obviously, the speed in testing improves tremendously. Consider the time required to set-up and perform CTB measurements manually for several channel loadings, several frequencies, and several different operating levels. Speed also promotes better characterization of a product. Prior to computer assisted testing, the CTB measurement would be sparsely sampled to confirm compliance. With a computer assisted test system a greater number of tests can be run in the same time, thus promoting better characterization of the product for CTB performance.

Documentation

The data from test results can be stored in computer files (disk), displayed on the CRT, and printed out for hard copy. Data printouts can be provided in easily interpretable form by the programmability of the system.

SUMMARY

This computer assisted RF test system has been in operation for about one year. At this time all of the major RF test objectives have been successfully realized and the system has been utilized to assist in several product evaluations.

Software for the test programs is continually being optimized and expanded to provide maximum versatility for testing the many different types of products required of the system. Program development has proven to be very friendly with the exceptional editing features and powerful commands of the system.

References

1. I. Switzer, "Spectrum Analyzer As A Computerized Proof of Performance Machine", NCTA Technical Papers, 1980.

CONNECTORS, CABLE AND "SUCK OUTS"

William J. Down

LRC Electronics, a Subsidiary of Augat, Inc.

ABSTRACT

The connector cable interface is discussed in detail and some possible ways to avoid center conductor pull back or "suck outs" are presented. The effects of normal and sub zero temperatures on the cable and its core to sheath friction are charted with some explanations of the use of loops in CATV construction.

INTRODUCTION

One of the major areas of concern in a coaxial cable system should be the connector cable interface, but in many cases the proper attention is not given to this very critical union, the failure of which always results in a loss of service. We spend many days in selecting the electronics and passives for a system but often relegate the selection of connectors and their installation techniques to a "last minute" effort that is not given the proper attention.

The intent of this paper is to make people aware of some of the causes of cable-connector interface problems and what may be done to avoid some of them. Most connector suppliers offer installation help of one kind or another varying from video tapes and written instructions, to on site training sessions with the installation crews. All of these aids should be used in the field, so that the people actually doing the work know the "hows and whys" of connector installation.

Field crews very often have difficulty adjusting when changing from one connector brand to another but most problems can be avoided by a small amount of instruction early, rather than waiting for them to get in real trouble later. I find that when training people to do installation or splicing type work, they do much better if they not only know how to install connectors but also why they should be doing it that way.

Most cables are made by foaming a dielectric over a copper clad aluminum center conductor and then drawing this foam covered wire into an aluminum tube that is a bit larger than the finished size. The aluminum tube is then drawn through many forming dies that now bring it down to the finished outside diameter and inside diameter of the sheath.

This process "builds in" several stresses in the cable which tend to relieve themselves in handling, installation, and more importantly temperature change. The center conductor itself has quite a bit of tension on it when the bonding agent and the foam dielectric is applied. This is very necessary to maintain the correct centering and the very critical dimensional requirements to build good cable. Since the center conductor is at no time stretched past its elastic limit it stays under tension after the foam is in place, and exerts its own force on the foam dielectric, trying to compress the foam and relieve the built in tension.

When the center conductor and foam are pulled into the outer tube, and the tube is drawn down to the proper size, other forces are now imposed on the center conductor and foam. The foam must be compressed to some extent so that there is some friction between the dielectric and the outer aluminum sheath. Please note that I said "friction" and not adhesion because the foam is not glued to the outer conductor, but depends on the squeezing of the foam to produce friction to hold the dielectric in place. (There are other manufacturing techniques that do use adhesion or glue on the outer sheath but these cables are not yet in general use). The complete cable manufacturing process must be very closely controlled so that the mechanical parameters are met, as the electrical specifications can be met whether or not the outside of the foam dielectric is squeezed or not. That is, it's possible to have cable with excellent return loss and attenuation characteristics that has no core to sheath friction whatsoever. These conditions can take place at room temperature (70°) but cold temperatures make conditions much worse, principally, because of the following reasons: Plastic (foam) has higher co-efficients of expansion than does aluminum by a factor of 5 or 10 to one. So that even though there was enough squeeze of the foam dielectric at room temperature to provide sufficient friction to keep a cable core in place, when it is cooled by 70 to 100 degrees the cable core or dielectric is actually floating free in the aluminum sheath and thus can do whatever it feels like, which is usually get shorter and pull out of the connectors if they will allow it. All of the conventional hard line aluminum cables manufactured as described behave in this manner.

The plot shown in Fig. I shows very dramatically how most current foam cables behave with temperature. A sample piece of cable is prepared with the center conductor exposed on one end and trimmed so that 8 inches of dielectric or core is left in contact with the outer sheath, as in Fig. II.

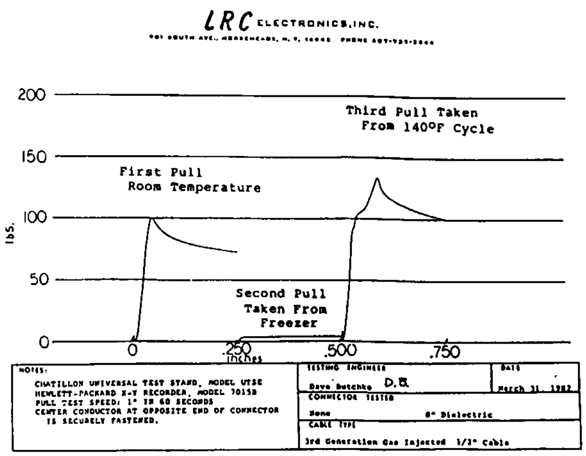
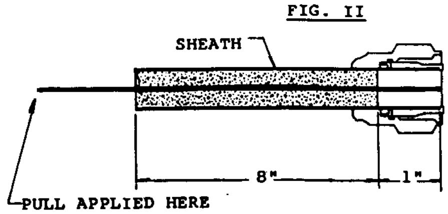


FIG. I

FIG. II



The jacket is anchored in a normal connector and a pull force is applied to the center conductor on the opposite end. The force required to move the cable core is shown in the vertical scale while the distance travelled is on the horizontal scale. In this test, the piece of cable was pulled three separate times, but all three plots are of the <u>same</u> piece of cable. The first pull was done at room temperature (approximately 70° F.) and the core held 100 pounds before it moved and was pulled for about 1/4 inch. The test piece was then cooled to about 0° F. and allowed to stabilize, it was then removed from the freezer and immediately pulled. As shown in the plot the cable only held 8 to 10 pounds and was pulled again for about 1/4 inch. The cable was then put in an oven and warmed to about 140° F. and allowed to stabilize, it was then removed from the oven and immediately pulled, and now took 100 pounds to move a slight amount, then rose to 130 pounds and slowly lost friction down to 100 pounds. Keep in mind this was the same 8 inch piece of cable and the plots show very well that this cable had no friction to hold the core in place when it was 0° F. but regains the friction when warmed.

I emphasize this because whenever there is a problem with center conductor pull back or "suck outs", the problem always appears at the connector and not in the cable. Since it is nearly impossible to manufacture cable that would have any core to sheath friction at -20° F. whatever. The only solution is to have the connector able to hold enough force to keep the center conductor in place. In order to understand this, one should consider a typical span of about 150 feet of cable. If possible most construction is done in the summer or in warm temperatures so it is not unreasonable to assume temperatures of 90° F. or more when the cable is installed. Most of the cable "suck out" problems occur in colder temperatures, which in some areas of the country can mean -20° F. or lower.

This means that the cable will undergo at least 110° change and with this much change it very much wants to be at least 2.3 inches shorter when cold than it was when it was put up. Much work has been done on proper sag and expansion loops at poles, etc., so that the cable does not destroy itself with temperature changes. Everyone who has been in cable for a while is familiar with the change from round bottom loops to flat bottom loops in order to spread out the stresses that are built up in expansion and contraction with temperature changes. Many papers have been written and many installation manuals produced that go into great detail as to how and where to put loops so that the cable sheath is not cracked due to movement with temperature changes.

We have come a long way and can now build cable plant that will maintain its integrity (by not cracking the cable jacket) for many many years, but we have generally not paid much attention to what happens to the cable center conductor through all of this. Think about it, the center conductor is made up of aluminum also, and it too would like to be 2.3 inches shorter with the cycling of the temperature by 110°. With no friction left in the cable and no loops, the connector must be capable of holding onto the center conductor hard enough to keep it from "sucking out" of the connector, which means that the center conductor must stretch a slight amount in order not to break. This will happen as long as the connector seizing device does not cut too deep into the center conductor as to weaken it past the point where it will stretch. That is, if the terminal cuts too deep into the center conductor and causes a fracture point that has a lower yield strength than that pull which will cause the center conductor to stretch, the center conductor will break away during the first cold temperature.

The connector designer must tread a narrow line in his calculations so that the center seizure terminal will hold the center conductor hard enough to stretch it but not so hard as to cut into it and cause a fracture point that has less strength than the yield strength of the aluminum. (Yield strength is generally defined as that point at which the elastic limit of the material is exceeded and the material now stretches).

In the ideal combination of connectors and cable in a CATV plant, one would have cable that had enough friction of core to sheath to keep the center conductor in place mated with a connector that held the center conductor with enough force to stretch the center conductor of the cable. I say ideal, because this would present a situation with a 100% safety factor. That is either the cable or the connectors would stand on their own and not depend on the other for support. In the real world this does not happen, most cable (through no fault of the manufacturer) has little or no holding friction at low temperatures and some connectors (due to manufacturing tolerances) do not hold the center conductor with enough force to stretch it. These conditions would seem to indicate that there is always going to be a problem, but we do have one other means of helping to avoid a problem, that is construction practices that are aimed at preventing center conductor pull outs.

If you take a piece of cable that is straight and pull on the core when it is cold it is very likely that there will not be enough friction to prevent the core from pulling out, but take this same piece of cable and form a loop of any kind in it and you will find that you have increased the friction by an appreciable amount. I say any kind of loop will provide this needed friction, but I feel you must stay with flat bottom loops to avoid the cracking of the cable sheath.

FIG. III

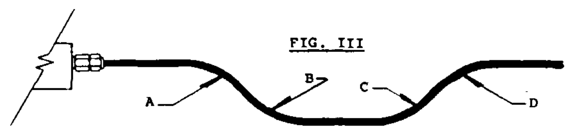
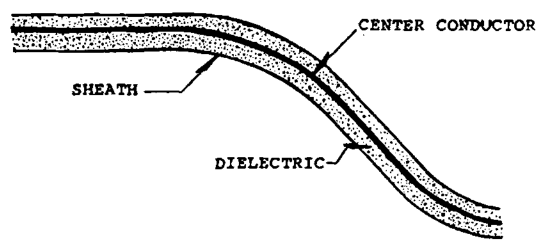


FIG. IV



In Fig. III note that there are the normal four bends present in the recommended flat bottom loop. A close up of these bends are shown in Fig. IV; note the sheath, dielectric, and center conductor. If one attempts to pull on the center conductor (which is glued to the dielectric) you have to pull the whole core around the bend which means it must be straightened coming out of the bend and bent going into it, thus causing considerable friction at points A, B, C and D in Fig. III. A normal flat bottom loop will add enough friction to generally keep the core from moving too far.

It is obvious then that I am strongly recommending <u>a loop at every connector</u> and not just a loop on one side of a device and not the other. In almost all of the cases of connector "suck outs" that have been investigated the pull out occurred where there was no loop present, even though the loop on one side of a device was sufficient to protect the cable sheath from cracking, it was not adaquate to prevent pull out of center conductor.

Another cause of connector failure is poor installation workmanship, generally due to not following the connector supplier's installation instructions. The common faults are:

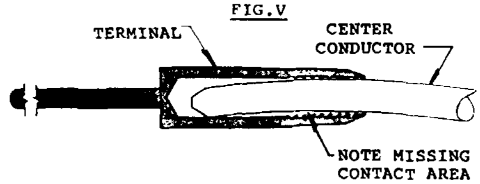
1. Improper preparation lengths(center conductor too long or too short). If the center conductor is left too long it bottoms in the connector terminal and prevents the sheath from bottoming in the connector ferrule, sacrificing gripping area on the sheath and possibly allowing the sheath to "let go" and cause a radiation problem.

2. Too short a center conductor preparation will limit the area of gripping available for the center terminal to hold the center conductor of the cable.

3. Improper cleaning of the center conductor of the cable will possibly leave plastic which can prevent the connector terminal from properly grasping the cable center conductor as the plastic provides a lubricant making the center conductor slide out easier.

4. A bent center conductor will limit the area that the teeth in the connector terminal can grasp the cable center conductor. (See Fig. V)

FIG.V



5. Score marks on either the cable sheath or the center conductor will cause stress points and hasten the failure of them.

6. Improper tightening of connectors seems to be the most prevalant flaw in construction. Different connector manufacturers write their instructions in different ways, some use torque specs, others so many turns and some have a positive stop, but whatever they say will be the right way to install that particular connector.

I know of no connectors on the market that do not function properly when the manufacturers instructions are followed, but real problems result if you install brand "A's" connectors to brand "B's" instructions.

(MAKE SURE YOUR PEOPLE ARE PROPERLY INSTRUCTED ON THE TYPE OF CONNECTOR THEY ARE USING).

CONTENTION VS. POLLING, A THEORETICAL LOOK AT POPULAR NETWORK PROTOCOLS IN CATV SYSTEMS

Michael Quelly & Eric Frech

E-COM Corporation
A Subsidiary of AM Cable TV Industries, Inc.
Stirling, NJ

ABSTRACT

This paper addresses a current area of some controversy. Systems employing contention and polling protocols are used over a range of services. The question always arises, "Which is best?" A limited amount of mathematical analysis is employed to demonstrate the strong and weak points of each and to reach some broad conclusions on the optimum applicability of these protocols.

INTRODUCTION

This paper addresses the relative applicability of each of the two most popular single-channel network communications protocols: polling and contention--in a modern multi-service CATV system.

First, a brief description of each protocol is presented. A discussion of the most common applications of each protocol follows, along with a summary of their relative similarities and differences. Third, a general discussion of the basic network design criteria imposed by typical data services carried on a CATV system is presented, along with a comparative study of the inherent capacity of both polling and contention networks to support such requirements.

NETWORK PROTOCOLS

Polling and contention are the primary network protocols used in broadband communications networks. Both protocols are well-suited to operation in the conventional tree topology of a CATV system. The decision to advocate one technique over another should be based upon a thorough comparative evaluation of their strengths and weaknesses relative to the application(s) at hand.

CONTENTION (RANDOM ACCESS)

This discussion is restricted to the Carrier Sense Multiple Access with Collision Detection protocol, commonly referred to as CSMA/CD. In the CSMA/CD network protocol, a terminal attempts to transmit whenever a message becomes ready. Before transmitting, the terminal checks for the presence of a carrier to determine whether or not the channel is busy. If the channel is unoccupied, the terminal transmits its message immediately. If the channel is occupied, the terminal waits before attempting to transmit the message. There are various methods used to determine how long to wait before attempting to retransmit the message. The method considered here is called 1-persistant CSMA/CD, since the terminal will transmit with a probability of 1 when the channel becomes available.[14] Once the terminal has successfully initiated a transmission, it monitors that transmission on its receive channel. If the data is received correctly as transmitted, the terminal assumes that no collisions have taken place. If incorrect data is received, indicating a collision, the terminal immediately ceases transmission and waits for a random period of time before attempting to retransmit. The throughput of a CSMA/CD system depends greatly on the method of calculation used by the terminal to determine the retransmission delay time. Importantly, the CSMA/CD algorithm is non-deterministic, i.e., a terminal's response time is a random variable, rather than a finite, calculable value.[12]

POLLING

Although several polling methodologies exist, this discussion is restricted to bus or roll-call polling. In the roll-call polling protocol, each terminal is interrogated in turn by the system controller.[12] As each polled terminal is provided with a response opportunity, it acknowledges by transmitting status information and data to the system controller. Even if the polled terminal does not have a data packet ready or available for transmission, the system controller acquires status information about the terminal. Upon the completion of the transaction, polling of the next terminal is initiated. The order used to poll all of the terminals is determined by the system controller, which can incorporate prioritization or any other method of sequencing required. Importantly, the polling algorithm is deterministic, i.e., in a given situation, a terminal's response time is a finite and calculable value.[12]

LOCAL AREA NETWORKS

The Local Area Network (LAN) has grown out of the requirements of the business and educational communities for a communications network that can handle a multiplicity of terminal-to-terminal and computer-to-computer connections. Such a network is generally confined to a localized geographical area, with a comparatively small number of users (10 to 1000), and normally transfers large blocks of data at infrequent times. Generally, LANs do not handle real-time applications, so that an occasional increase in network delay is of no real consequence. Carrier Sense Multiple Access with Collision Detection (CSMA/CD) has developed as the logical choice to satisfy these requirements.

In summary, a LAN is characterized by small geographic size serving a small number of users handling "bursty" transmissions of data.[14]

MULTI-SERVICE COMMUNICATIONS NETWORKS

A Multi-Service Communications Network can support a wide range of services such as television (with pay service control, PPV, and IPPV), home security, medical alert, utility meter reading, home banking and shopping, electronic mail, information retrieval, personal computer interfacing, games, videotex, and system status monitoring. The user base of such a system can range from 1000 to 250,000 subscribers. Some of these services are real-time applications (home security and medical alert, for example), that can tolerate a controlled amount of network delay but that must be assured of nearly immediate access to the system. The multi-service network does not exclude those functions normally provided by a LAN.

In summary, a Multi-Service Communications Network is characterized by large geographic size serving a large number of users producing a continuous transmission of data.

NETWORK DESIGN CRITERIA

Three important network design criteria are imposed by the services provided by a typical Multi-Service Communications Network.

First, the network must be optimized to handle the varying data throughput requirements of the different services carried. For example, a home security terminal requires one bit per second to monitor an alarm and provide a one-second response time. In contrast, a videotex terminal typically requires 2000 to 3000 bytes per active minute. Utility meter-reading services require transmission of approximately 6 bytes per meter per hour to provide hourly readings. The ability to efficiently handle the wide variation in data throughput associated with a diverse variety of services is a primary consideration in the design of an effective Multi-Service Communications Network.

A second design consideration is the wide variation in scheduling required by such an array of services. Some services require continuous or frequent monitoring of the status of remote terminals, while others do not. Citing the above examples, utility meter readings may be required at regular hourly intervals, while security alarms occur at random and must be serviced with a high priority relative to other services. A successful Multi-Service Communications Network must provide convenient and compatible scheduling and prioritization facilities.

Third, as new services are developed for inclusion into a Multi-Service Communications Network, the physical integrity of that network must be assured. Utilities considering the adoption of meter reading services must be assured reliable and continuous operation. In particular, security applications demand that the status of a remote terminal be known at all times. For these and other reasons, network global status monitoring has become an important design consideration.

COMPARATIVE EVALUATION

The throughput of a polled network is limited by the communications overhead associated with the successive poll and poll-acknowledge messages flowing between system controller and terminals. CSMA/CD's primary strength lies in its lack of overhead. In the absence of a continuous flow of poll and poll-acknowledge messages, extremely fast response times are theoretically possible. In an application that features a low probability of message collisions (as in a system with few terminals or a low message arrival rate per terminal), these fast response times do occur.

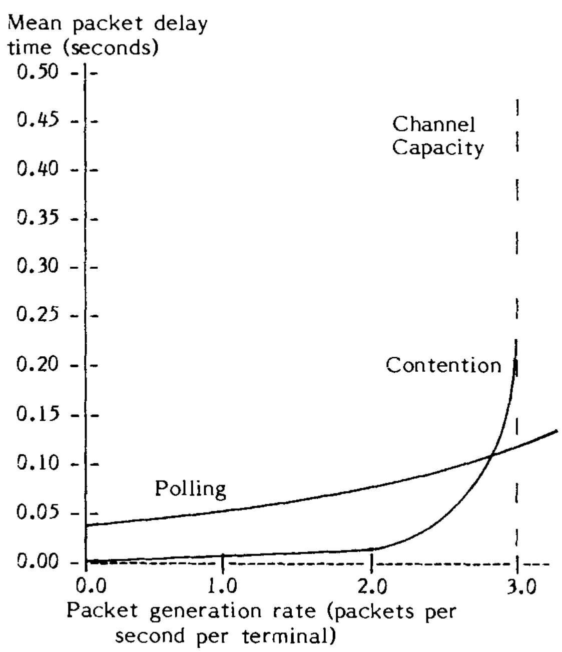
The following graphs are the result of simulation programs written in BASIC for a TRS-80 Model III. Many runs of the simulation programs were made with different system parameters to study the sensitivity of the network to these parameters. Details of the models used in the simulation, along with supporting mathematical analysis, may be found in the Appendix.

The simulations consumed many hours of computer time. As a result the data for high loadings is not yet complete. At high loadings a CSMA/CD system experiences a large number of collisions and the individual packet delay varies widely. It appears that some delays will be very large, thereby further reducing the allowable system loading where short delays are mandatory. Further data is being taken to quantify this effect.

Figure 1 displays the mean packet delay as a function of message rate for a small network (100 terminals) with a long mean message length. The random access network produces lower mean response time than the polled network until it nears its theoretical maximum throughput. Then the polling system provides a lower packet delay. Figure 2 shows the same simulations for a network with 1000 terminals and shorter mean message lengths. As the curves show, there is no doubt that under conditions of low and medium loading, the contention system achieves shorter mean packet delays. However, other performance parameters must be considered along with their relationship to each proposed service.

The performance of the networks in the overload condition should be considered. In the contention system, when the system is overloaded, very few messages get through. It is difficult for a network to recover once this state is reached. When the polled system is overloaded it simply slows down. Because of the centralized control implicit in a polled system, it is possible to alter the polling sequence so that high priority terminals are still serviced at an adequate rate.

The polled network operates in full-duplex. Different information may be transferred in each direction on the network simultaneously. This two-way transfer of data makes possible 100% utilization of the data channel, i.e., data can be transmitted continuously in both forward and reverse directions. The single-channel CSMA/CD terminal operates in half-duplex. Even though the terminal must monitor the receive channel for collision detection (while transmitting) in what is essentially a full duplex operation, information is transferred in only one direction at a time.

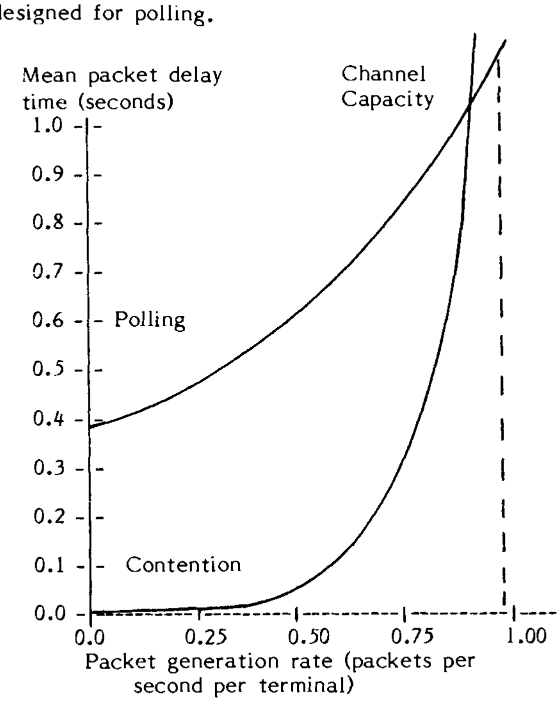


SIMULATED SYSTEM
Mean propagation delay = 182 microseconds
Mean packet length = 100 bytes
Number of terminals = 100

Figure 1

One of polling's strengths is the ease with which complex scheduling and prioritization functions can be implemented. Since the order and frequency of polling are under direct system control, terminals may be polled in accordance with the scheduling and priority requirements of the services which they provide. In addition, adaptive polling strategies may be employed to control network loading. In a CSMA/CD system, the transmission rate of each terminal is individually controlled by that terminal. Scheduling control must be implemented by some external means since it is not inherent in the operation of the contention protocol. A special terminal may serve as a network traffic controller to inform terminals of their scheduled transmission rate.

In a security system the proper operation of each terminal is vital to the security of the installation. Failures, which may be caused by cut cables or tampering, should produce immediate alarms. In the polling protocol, the incorporation of status information into the poll acknowledgement provides automatic global status monitoring. This is quite difficult to implement in a random access network, since there is no automatic notification produced for a terminal failure. A polling-type mechanism may be employed, using one of the terminals as a system monitor to check the operation of each of the other terminals in the network. This type of polling is, however, less efficient than that used in a network designed for polling.



SIMULATED SYSTEM
Mean propagation delay = 182 microseconds
Mean packet length = 10 bytes
Number of terminals = 1000

Figure 2

The importance of proper terminal installation and maintenance cannot be overlooked. The system operator must be able to verify signal levels and error rates of individual terminals in order to verify both correct installation and continuing operation. If a bad terminal is installed, and the error-correction circuitry in the network protocol compensates for the terminal's bad performance, the operator may never know of the failure. The ability of a polling protocol's central controller to determine such an event is difficult to implement in a contention network, without the addition of a polling mechanism.

Due to the centralized nature of polling, the system controller tends to be complex both in equipment and software. The special reliability requirements of a system with highly centralized control contribute to this complexity. In a contention system, the terminals are more complex so that the system cost on a per terminal basis may be considerably greater. While it would appear that CSMA/CD's distributed nature gives it reliability advantages over polling, the need for specialized terminals to control network operation tends to reduce this reliability advantage.

CONCLUSIONS

In conclusion, it should be clear that the selection of a network protocol that can accomodate the wide variety of data services available to a CATV system must be based on several important requirements:

1. capacity to handle the throughput load requirements of all services carried;
2. capacity to handle timing and scheduling requirements of these sevices;
3. need to insure the physical integrity of the distribution system supporting these services;
4. need for automatic notification of terminal failure;
5. need to have traffic flow monitored and controlled to provide billing information;
6. need to present the lowest individual terminal access time possible and practical for each service.

This paper has attempted to provide the system designer with a basic understanding of the abilities of both polling and contention protocols to handle these design requirements. While the contention protocol has largely evolved from a specific operational system need (such as presented by a Local Area Network), polling has been used to address a number of problems not unique to any one application. It is important not to let certain individual aspects of any one protocol dictate its use in a system that it cannot fully support.

The CSMA/CD architecture is clearly well suited for the multiple host computer, multiple user terminal environment typical in universities and various commercial complexes. Here the probability of one node communicating to any one of the other nodes is usually comparable.

The polled system offers many advantages in situations built around common sources of information, common points of control, services requiring frequent status monitoring and deterministic service requirements as often encountered in CATV residential services. Accepting the intrinsic delays, a polled system can transfer more data in a given channel and does not suffer paralysis in overloaded conditions.

In closing, the following thought: the system should not be selected to fit a protocol, but rather the protocol should be selected to fit a system.

APPENDIX

MODEL SYSTEM

In order to compare polling and random access communications networks, it is necessary to select a model. The model chosen is used in modeling both the polling and the random access protocols to provide an accurate comparison.

Messages are generated at the terminals using a poisson distribution (exponentially distributed inter-arrival times). Geometrically distributed message lengths are assumed, with maximum message length constrained to fall below 251 bytes, the maximum data field length in the communications protocol we are considering.

We make the assumption that each terminal is independent of the others. Since we are comparing two systems that perform the same services, the processing time for the packets is neglected. This is reasonable, since in practice the systems run in a multiprocessor environment where the communications processor is separated from the processor handling the actual service.

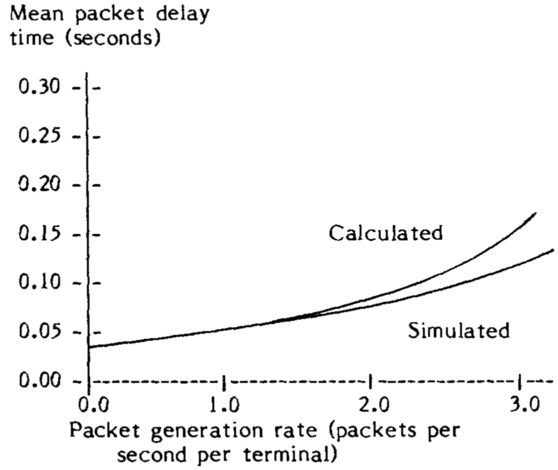
The propagation delay through the network is considered to be a constant. The average delay between two points in the network is considered to be one-half the maximum network delay. This is a reasonable assumption for a network where the terminals are uniformly distributed throughout the network. For a fifty-mile CATV system using .7 as the velocity constant in the cable, we arrive at 384 microseconds for the delay to the farthest point in the system. One half of this number, or 7 byte periods, is used for the one-way propagation delay through the network.

In our model, RF transmitters are assumed to turn off in zero time and collisions are detected instantaneously. This allowance reduces the period of vulnerability of the contention message, which tends to reduce the number of collisions.

The data rate used for our simulation is 307.2 kilobits per second, yielding a byte time of 26 microseconds. The communications protocol is similar to X.25. Data is synchronous with 8-bit bytes. The message formats are shown in Figures 3 and 4.

MATHEMATICAL ANALYSIS

While the mathematical analysis of a polling system is inherently difficult due to the interdependence of the status of messages waiting at message sources, a similar analysis of contention is much more difficult due to its non-deterministic nature.[7] Konheim and Meister, however, have carried out the analysis of a polling model similar to ours, i.e., poisson arrival processes at each message source, geometric message lengths, symmetric equilibrium statistics at all sources, etc.[2,4,12] Calculations of mean inbound packet delay, employing formulas developed in this analysis, tend to support our simulation results. Figure 5 compares simulated and calculated delays for a small network (100 terminals) with long mean message length (see also Figure 1).



POLLING
Mean propagation delay = 182 microseconds
Mean packet length = 100 bytes
Number of terminals = 100

Figure 5

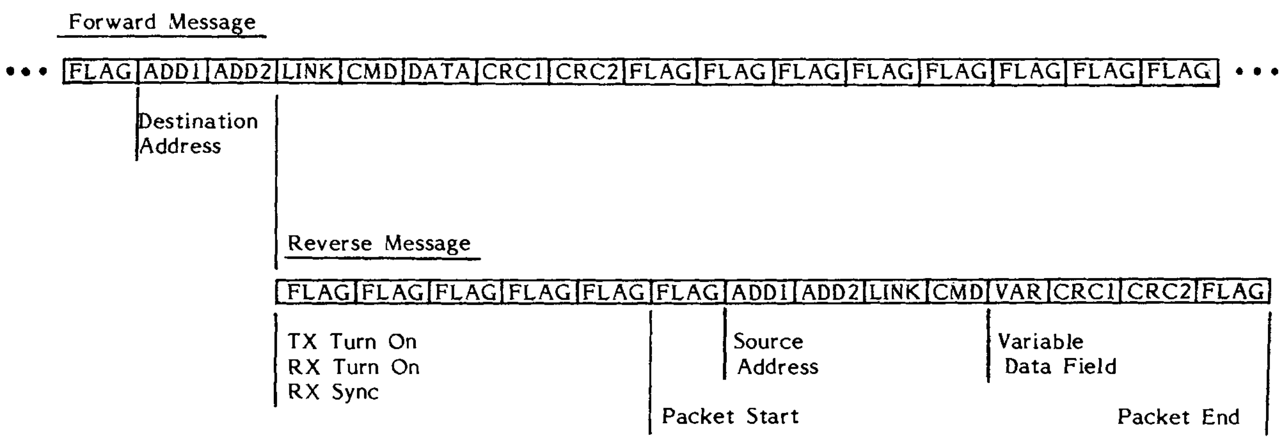


Figure 3 Polling Packet Format

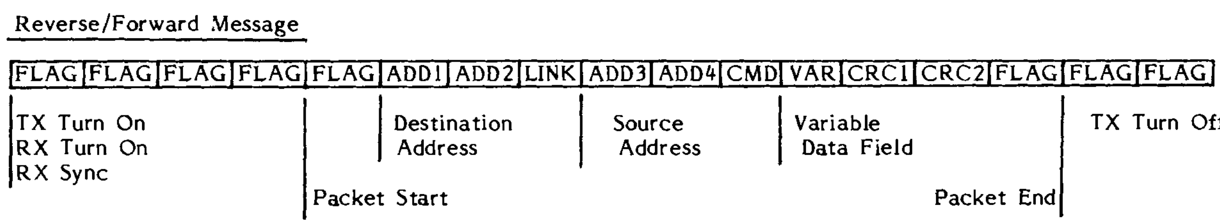


Figure 4 Contention Packet Format

Expected value of the packet delay:

$$E(D) = \frac{t}{2}(1-r) + \frac{NVk}{2}\frac{1}{(1-Nr)} + \frac{(1-r)k}{2} \qquad (1)$$

E(D) = expected value of the packet delay (seconds)

Variance of the number of data units arriving in k seconds:

$$V = \frac{lk}{p^2}(2-p) \qquad (2)$$

V = variance (bytes^2)

Mean Scan Time (the mean time required to poll all the units):

$$t = \frac{L}{1-Nr} \qquad (3)$$

t = mean scan time (byte periods)
N = number of terminals
r = traffic density (unitless)
L = walk-time (byte periods)

Traffic Density (the average rate of data flow in the network):

$$r = \frac{lk}{p} \qquad (4)$$

r = traffic density (unitless)
l = packet rate (packets/sec)
l/p = mean packet size (bytes/packet)
k = time interval (sec/byte)

Walk-time (the irreducible portion of the time required to poll all the terminals):

$$L = N(C_F + C_R + 2d + D_{min}) \qquad (5)$$

L = walk-time
C_F = constant portion of the forward message
C_R = constant portion of the reverse message
D_{min} = minimum length of the data field

BIBLIOGRAPHY

1. Bond, Ralph C. "Collision Avoidance Improves Broadband Bus Networks." Systems & Software. November 1982, pp. 67-71.

2. Chu, Wesley W., Alan G. Konheim. "On the Analysis and Modeling of a Class of Computer Communications Systems." IEEE Transactions on Communications. Vol. Com-2, No. 3, June 1982, pp. 645-660.

3. Hillier, Frederick S., Gerald T. Lieberman. Operations Research. San Francisco: Holden-Day, Inc., 1974.

4. Konheim, Alan G., Bernard Meister. "Waiting Lines and Times in a System with Polling." Journal of the Association for Computing Machinery. Vol. 21, No. 3, July 1974, pp.470-490.

5. Kuo, Franklin F. Protocols and Techniques for Data Communications Networks. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1981.

6. Martin, James. Systems Analysis for Data Transmission. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1981.

7. Meisner, Norman B. "Estimating the Throughput of Broadband LANs." Systems & Software. November 1982, pp. 75-77.

8. Meyer, Paul L. Introduction to Probability and Statistical Applications. Reading, Mass: Addison-Wesley Publishing Co., 1970.

9. Puzman, Josef, Rodoslav Porizek. Communication Control in Computer Networks. New York: John Wiley and Sons, 1980.

10. Riley, Wallace B. "Local Area Networks Move Beyond the Planning Stage." Systems & Software. November 1982, pp.50-60.

11. Sasieni, Maurice, Arthur Yaspan, Lawrence Friedman. Operations Research Methods and Problems. New York: John Wiley and Sons, 1959.

12. Schwartz, Mischa. Computer Communication Network Design and Analysis. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1977.

13. Sharma, Roshan Lai, Paula J. T. de Sousa, Ashok D. Ingle. Network Systems. New York: Jan Nostrand Reinhold Co., Inc., 1982.

14. Tanenbaum, Andrew S. Computer Networks. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1981.

CURRENT CONFIGURATIONS AND FIELD INSTALLATIONS OF MULTIPLE SERVICE COMMUNICATIONS SYSTEMS

By

Robert V.C. Dickinson

E-COM Corporation
A Subsidiary of AM Cable TV Industries, Inc.
Stirling, NJ

Slowly but surely, CATV facilities are being employed to carry new revenue-producing, non-entertainment services. While businesses are developing slowly, many believe that a large portion of the cable operator's revenue in the future will be provided by non-entertainment services. There have been quite a number of test projects and commercial efforts instituted where two-way cable transmission has been employed.

There are over 50 operational security, fire and burglar alarm systems on cable according to the January, 1983 NCTA Cable Enhanced Services Guide. These systems are largely residential in nature. Other systems addressing the residential market include energy management (utility meter reading and load shedding) and a range of videotex services including home banking and shopping plus informational services. Institutional networks have been established on both conventional CATV systems and private systems where all types of data are carried, ranging from energy management and status monitoring to extensive interconnection of computers and computer peripherals. All in all, there has been a good deal of activity and experience gained in utilizing the cable to develop new revenues and, in the process, serve the community. It is the purpose of this paper to briefly describe selected examples and to philosophize a bit upon the techniques and controls necessary to effectively and efficiently utilize cable networks for carriage of two-way non-entertainment services.

EXAMPLES OF CURRENT PROJECTS

The examples that follow have been selected to illustrate various phases of current activity in the field and to provide a backdrop for the following discussion.

Warner Communications has probably the highest deployment of two-way terminals which are involved in entertainment control (QUBE) and security. There are in the order of 100,000 interactive QUBE terminals controlling converters and allowing upstream ordering and opinion polling plus about 10,000 special terminals employed for residential security. The QUBE system is a good example of the utilization of the technology and hardware employed by one service to support a second. Businesswise, the entertainment control functions are totally separate from the security functions since security monitoring is implemented by a separate business entity. The QUBE system performs well, although a number of problems had to be solved in order to achieve reliable operation. Warner found it necessary to use feeder switches synchronized with the polled data system to reduce the amount of noise competing with the upstream signal. The noise problems encountered were predominantly the result of ingress rather than of noise floor summation from the high number of subscriber terminations. In the security services special provisions were needed to cut down the noise-induced false alarm rate and telephone dialers were redundantly employed to assure higher reliability of security alarm transmissions.

Manhattan Cable TV operates one of the oldest data transmission experiments in the industry, which has been operating as a business for about 9 years. This venture developed around the commercial data transmission market in Manhattan. Rather than being faced with noise contribution from every residential drop, the MCTV system was first configured with direct feeds back to bridger ports wherever possible, thereby eliminating the need for two-way capability in the distribution system. Later, as the business built up, Manhattan Cable was able to switch most of the data circuits to an institutional network thereby avoiding the entertainment system entirely. While most of the circuits in Manhattan Cable are point-to-point, they are being used for a range of service by totally independent customers. Frequency Division Multiplexing (FDM) is used throughout to separate the services in the dedicated mid-split system. While truly a multi-service network, this situation is somewhat special and does not represent a "typical" cable system configuration.

The Times Mirror experiment in their Mission Viejo, California system utilizes Telidon as the basic videotex format for information, shopping and banking services. Their experiment included customers served by both telephone and cable circuits. The cable circuits were implemented on a polled TRU-NET 100 system supplied by E-COM Corporation. This polled system was arranged to intercept user requests and provide transparent circuits from the users to the Telidon host computer via 28 telephone ports. The polled circuit included diagnostics which monitored performance with error counters for each customer modem and was capable of isolating specific modem responses individually to analyze levels, modulation, etc. While the system was not used for simultaneous meter reading and security, these functions were included in the interface modems and certain units tested throughout the project. Dynamic polling assignments were employed so that all units, whether active or inactive in the videotex interchanges, were polled no less frequently than every 10 seconds providing continuous status monitoring of the system. Had security been implemented, alarm status would also have been checked no less frequently than every 10 seconds regardless of the videotex loadings. A telephone modem was installed on a separate computer port so that system diagnostics could be performed from the E-COM plant in New Jersey. By monitoring the error counters which were kept on all units, it was possible (from New Jersey) to sense system ingress build-up and point out the area in the system where ingress was occuring. This was an important feature since the cable system was an older one and ingress was a problem. The section implemented for two-way was small, therefore, feeder switches were not employed. Had they been required, they would have come under the control of the same polling system and would not have posed a synchronization problem.

The Cox INDAX system has been deployed in San Diego and Omaha. INDAX is implemented using a contention protocol. Indax controls entertainment services as well as provides banking and shopping at home and a wide variety of informational services. The home terminal includes the converter and generates both alphanumerics and graphics for display on the TV set in the videotex mode. Technically the system performs well and has experienced a minimum of ingress. This is due to the extreme care taken in preparation of the segments of the system which are in use. There are several hundred terminals in service in San Diego and Omaha. There are 40 channels available upstream and 80 downstream. Excess downstream channels are provided to carry broadcast information. Diagnostics to locate ingress include the use of geographic channel assignments as a means of sectioning the system.

Dow Chemical employs broadband networks (private CATV systems) in 26 plants around the world. The largest utilizes about 100 miles of plant and employs 550 point-to-point or multidrop modems. This system, which includes other (non-entertainment) services, is running out of spectrum. It is important to note that data transmission on private CATV systems is becoming increasingly important in a number of industries. As far as operational problems at Dow are concerned, there are enough data modems used on the more heavily loaded systems to make composite triple beat an important source of degradation. In order to control this problem, system balance must be maintained, and a constant vigil must be kept to assure that the modem operating levels are kept within a fairly narrow range. Ingress has often been a problem in their systems. It was soon determined that the cost of "shortcuts" is too high. The cable system must be built well using the best quality equipment including, of course, EMI connectors. Drop cables are run in quad-shielded RG-6/U and are kept as short as possible (usually no more than 25 feet). Good "F" connecters are a must. On the poles they have found that flooded jacketed cable is somewhat more durable, developing less cracks, probably due to the damping of the jacket and flooding compound in conditions of wind and vibration. As these systems are constantly monitored for leakage with equipment in trucks and carried by personnel, these systems are well-maintained and produce a very high availability which is a necessity in commercial applications.

OBSERVATIONS

Probably the major problem encountered in all of the systems listed above (and generally in implementation of two-way services) is that of ingress. It is the feeling of many that ingress can be controlled, and indeed it is being controlled in quite a number of systems. One cable operator who was interviewed during the preparation of this paper reported that, after solving the initial problems of two-way system integrity and establishing a comprehensive monitoring program, it was observed that there were more downstream system faults than there were in the reverse system. This speaks well to the point that two-way cable plant can be effectively constructed and maintained.

The data systems, however, must be robust enough to operate with finite error rates. If the data transmission system is equipped with provisions for error detection (and possibly error correction) then it can be reliably employed and function satisfactorily in all but cases of major ingress interference. Note that error detection provides a good handle on system performance and expected data integrity. Error correction, on the other hand, may or may not be required. For instance, in security and utility meter reading services, it is important that the data be correct. Security alarms should be immediately verified or contain error- correcting codes or redundancy to make the probability of error vanishingly small. On the other hand, a large videotex message which sustains a single or even a few errors often does not produce visible degradation in the displayed product. If the videotex is being employed, however, for banking or shopping, then at least certain portions of the message must have high integrity. These considerations lead to the requirement for flexibility in error control which is at the disposal of the cable operator and those to whom he provides transmission service.

E-COM has data transmission equipment installed on cable systems in the United States and in Europe. Our technicians have participated in data system start-ups in many of these locations. One of the first matters of concern is the "health" of the reverse transmission system of the cable network. In many cases a good deal of ingress is encountered. It is sometimes apparent that the cable technicians do not appreciate the impact of ingress on upstream services. Many of the signals that are seen vary considerably in amplitude, such as those originating from broadcasts and other services on the shortwave bands. To the uninitiated, the sub-band can be a very confusing combination of many signals coming from totally unknown sources. We have made it a practice to pick up a low cost battery-operated amplifier with built-in speaker from the local electronics store and use it to monitor the vertical output of a spectrum analyzer. Then, instead of viewing a nondescript blob of signals in one of the shortwave broadcast bands, we instruct the technician to narrow down the resolution of the spectrum analyzer, select a single signal and go to "zero sweep" . In this mode, the spectrum analyzer becomes an AM detector and the modulation can be heard. This is a great help in identifying signals; as a matter of fact, these amplitude modulated signals include some unexpected signals such as wireless telephones, harmonics of broadcast stations, and the like. Identification of the signals by the modulation gives the technician a much better idea of where the signal originates and hence where it may be entering the system. Once a familiarity is gained with the general signal content of the sub-band and the times when certain types of signals are at maximum amplitude, these rough parameters can be used as an indication of the overall integrity of the reverse path in the cable system. Using the spectrum analyzer and the audio amplifier in a similar manner, one develops an ear for recognizing the cable data channel sounds. These are very distinctive, particularly in a polled system. A change in the character of these sounds can often signal certain types of malfunctions.

Another phenomenon that occurs in the sub-band is the appearance of signals at 6 MHz intervals (referred to zero frequency). These signals are the result of intermodulation between the downstream TV carriers. This intermodulation is usually due to rectification in poor or corroded joints such as connectors on tap housings and is much more prevalent in older systems. In one such system, this effect was used as a monitoring parameter since when everything was tight, the intermodulation was absent. As time went by, corrosion in the fittings would build up and the 6 MHz "markers" would appear. The engineer on that system had set his own limits; after these "markers" exceded a certain threshold, he would dispatch technicians to affected areas of the system to tighten or replace fittings.

Before we leave the matter of ingress, there is a final point which must not be overlooked. Where ingress is present so is egress. Egress in the vernacular is simply "signal leakage". Signal leakage from cable systems interferes with over-the-air communication and broadcast services. Signal leakage is illegal. It is constrained by two sections of FCC Part 76. Under part 76.605 (a) (12) you must conform to the standard of "20 microvolts per meter at 10 feet", etc. This is an onerous task but it is possible in a well constructed and maintained cable system. Under part 76.613 you must cease operations if you interfere with any other service licensed by the FCC. In many cases, elimination of such interference can be extremely difficult and requires diligent effort and a good deal of statesmanship. Failure to comply with the above will sooner or later result in many segments of the communication community battering the cable industry, probably to the point of losing channels. The FAA and Amateur Radio situations have already become very significant. It does not take much imagination to see that many other radio service users could follow suit. Some operators are successfully coping with these problems (which include one-way systems as well as two-way); those who do not address them effectively will doubtlessly cause the entire cable industry to suffer for their shortcomings.

E-COM's TRU-NET 500 system is now being deployed in the field to handle a variety of services including utility meter reading, load shedding, security, pay television control, home computer interfacing and videotex. This system is polled and utilizes distributed intelligence. At the headend the System Communication Controller (SCC) communicates with Area Control Units (ACU's) throughout the system which, in turn, communicate with discrete modules that interface the various services. The system utilizes a three-position feeder switch in each Area Control Unit which is controlled as a function of the normal polling sequence. Use of feeder switches is usually unnecessary for normal operation although they are essential for the isolation of ingress.

The TRU-NET 500 system checks errors on all messages and accumulates error counts for each unit in the system. Analysis of these error counters often gives warning of major difficulty providing time to service developing system leaks. The diagnostic package for the TRU-NET 500 stores the cable network topology which is constructed through entry of the actual cable system elements (including cable, amplifiers, passives, power supplies, etc., as well as the TRU-NET system components). In other words, the SCC contains a "map" of the entire cable system. In the case of mass failures, additional software compares the fault distribution with the actual system configuration and can thereby pin-point the problem. The Area Control Units tend to segment the system so that communication failures between customer modules and the ACU (due to ingress on the customer drops, for example) are limited to a maximum of 250 customer modules. As a matter of fact, when the Tier-Guard Tap (TGT) is employed for premium TV control, the upstream path of each drop may be turned off, thereby restricting ingress over the entire sub-band. The TRU-NET 500 system has been designed with maintenance of real life CATV systems in mind, while simultaneously accommodating a wide range of subscriber services.

The title of this paper includes the term "multi-service". It is more and more apparent that there will be multiple services to be carried on cable systems. Even though the future services are as yet undefined, it is apparent that their numbers will continue to increase. In addition, certain services produce only moderate revenues that often make them economically unacceptable if implementation is performed on a stand-alone basis. We feel that these factors and the problems that exist in attempting to mix multiple stand-alone services in the cable network should guide the development of flexible data systems which can handle a variety of services. Properly configured, such systems can be high in capacity and low enough in cost that virtually any service can be operated economically and thereby justify the initial installation. Additional service can then be added later with even better economics leading to higher revenues as these new services are implemented.

CONCLUSION

Multi-service communications systems are a must for the future of ancillary service carriage on CATV systems. They must be two-way and therefore demand designs capable of operating and controlling real life CATV situations, not the least of which is the presense of ingress. Cable systems must be designed and monitored to eliminate ingress to the greatest possible extent in order to support these communications systems and to protect the industry from outside pressure as the result of leakage interference.

Many pioneers in new services have at least partially reached these goals. Success in these areas means more cable system revenues and more service to the community.

DATA NETWORK PARAMETERS

Thomas J. Polis

Communications Construction Group, Inc.

The Cable Television Industry has developed over the years many thousands of miles of coaxial broadband cable communications systems. The primary use of these systems has been for the delivery of entertainment services into the home. Even the limited data which has been introduced into our systems is used for control of entertainment offerings.

This paper will deal with the business applications of data networks and the parameters which will be viewed by the end user as critical to his data communications needs. These parameters will include: 1)end to end throughput 2)queuing delay 3)error correction 4)blocking probabilities 5)delay - throughput curves and many more which are inter-related to the network design.

The entrance into the business data communications arena will require us all to learn new skills to both design and market these services.

When dealing in the business of providing entertainment over our coaxial networks we have come to learn the parameters by which we are either accepted or rejected by the consumer. These parameters boil down to basically two: 1)picture quality and 2)reliability. These are, of course, subjective parameters but can be broken down into measurable units of performance such as noise, second and third order distortions, low frequency disturbances, failure rates, and a whole host of others used daily in our industry. By proper selection of the measured parameters the subjective ones viewed by the subscriber will be assured.

The same basic philosophy will hold true in the potential business user of data communications circuits. That is, he has his subjective values of the service provided and these values can be related to measurable parameters. Before we discuss these parameters, we must first realize that there are two primary types or classifications of users:

1. Those with high volumes of data traffic but limited destinations
2. Those with low volumes of data traffic but many possible destinations

While variations exist between these two extremes this paper will deal only with the extremes.

In case number 1, the solution is fairly simple in that direct full time circuits would most likely be established for this user. He would, in all probability, be very sophisticated in his network approach and only require the line provider to meet bandwidth and noise limitations.

Case number 2 is quite another story. From an economical stand point it makes sense to share the line amoungst many users thus take full advantage of the resources available to us.

It is interesting to note that with either classification of user the subjective performance of the system or network is the same "accurate data transfer with minimum response time available on a full time basis". The performance measures and considerations will be substantially different for the two classifications to achieve this subjective performance criteria. In case number 1 direct connection of Data Terminal Equipment (DTE) over a wide band, low noise circuit with redundancy will provide the desired results. In case number 2 an elaborate multiple access scheme with message processing will be required to serve all users.

PERFORMANCE MEASURES

In the following list of performance measures the first seven are applicable to both cases. The balance are more related to the multiple access networks.

1. Transfer Rate of Information Bits (TRIB)

This is the net rate at which information "BITS" can be transmitted across the network and be accepted by the sink. This is measured in bits per second and is closely associated with the bandwidth assigned.

2. Bit Error Rate (BER)

This is the number of bits which are changed by the network from those originally transmitted. This measure is closely associated with "noise" (both thermal and impulse) within the assigned bandwidth.

3. Residual Error Rate (RER)

The ratio of bits which are in error that have not been detected or corrected by the error correction process.

This is the true measure of the information transfer accuracy in any network.

4. Reliability

This is the probability that all of the devices in the network will perform without failure over a specified time or period or amount of usage.

5. Availability

This is the portion of a selected time interval during which the communications path is capable of performing its' assigned function. It is closely tied to reliability in that both mean time to failure and mean time to repair are considered. This is some times referred to as "on time".

6. Probagation Delay

The time taken by a one bit signal to move from the input of the network to the output. In wide area cable systems this will be variable with the distance to be covered.

7. Turnaround Time

The time taken for the circuits to reverse from transmit mode to receive mode. In two way cable systems, this is usually determined by the modem and is usually negligible.

8. Channel Establishment Time

The time required for the network to establish a connection between the source and destination DTE.

9. Response Time

The time interval from the instant that the last bit is sent from the source DTE to the instant the first bit is received at the destination DTE.

10. Message Delay

There are three ways of stating message delay:

a) End to End Delay

The time taken from input of the first bit in a message at the source DTE to the time the last bit in a message is received at the destination DTE.

b) System Delay

Has the same definition as response time.

c) Insertion Delay

The elapsed time from the transmission of the last bit of a message from the source DTE to the receiving of the last bit of the message at the destination DTE.

For the user the most meaningful is the end to end delay.

11. Blocking Probability

This is the parameter which indicates to the user that his message may be blocked due to other users occupying the capacity of the system. It is usually stated in percentage.

12. Buffer Occupancy

Since the load on the network is variable the capacity will be determined by laws of probability, thus "buffers" or storage areas will be used to handle the maximum foreseeable load. Messages will be lined-up or "Queued" for insertion into the system. During overloads the buffer may "overflow" causing messages to be lost. This can be stated as a probability or percentage.

13. Index of Utilization

This is the probability that the network is not idle.

14. Throughput

This parameter is, or should be, a collective statement of the system capability (much like channel loading of our distribution systems) to handle the traffic demands. While there are many ways to state this parameter the most meaningful is "Net Throughput Rate" which is in effect TRIB. This statement of throughput considers and nets out error correction delay and overhead bits. To make sense, this parameter must be stated at some finite delay.

This parameter can be stated:

$$TRIB = \frac{K_1 \ (M - C)}{N_T \ [\frac{M}{R} + \Delta T]}$$

Where:

K_1=Information bits per character

M =Characters per message

R =Characters per second (bit rate)

C =Overhead characters per message

N_T=Number of retransmissions *

T=Time between blocked transmissions

*ARQ (Automatic Repeat Request) error correction scheme.

Based on these parameters a potential customer for a multiple access data communications system would desire to see specifications such as:

Data Rate = 1.544 MB

TRIB = 80% Data Rate @ 2 message delay

BER = 10 - 6

RER = 10 - 10

Availability = 99%

Response Time = < 2 second maximum

Blocking Probability = .01% maximum

Overflow Probability = .001% maximum

Index of Utilization = 60%

In addition to these parameters two other areas must be considered for multiple access networks:

1. Transparency

Messages sent over the network should not be mistaken for routing, flow control, or network control codes. This is accomplished by "bit stuffing protocols".

2. Security

The network must have the ability to protect the information being transmitted over it from loss, disclosure, or modification. This can be accomplished by authorization groups or by cryptograms.

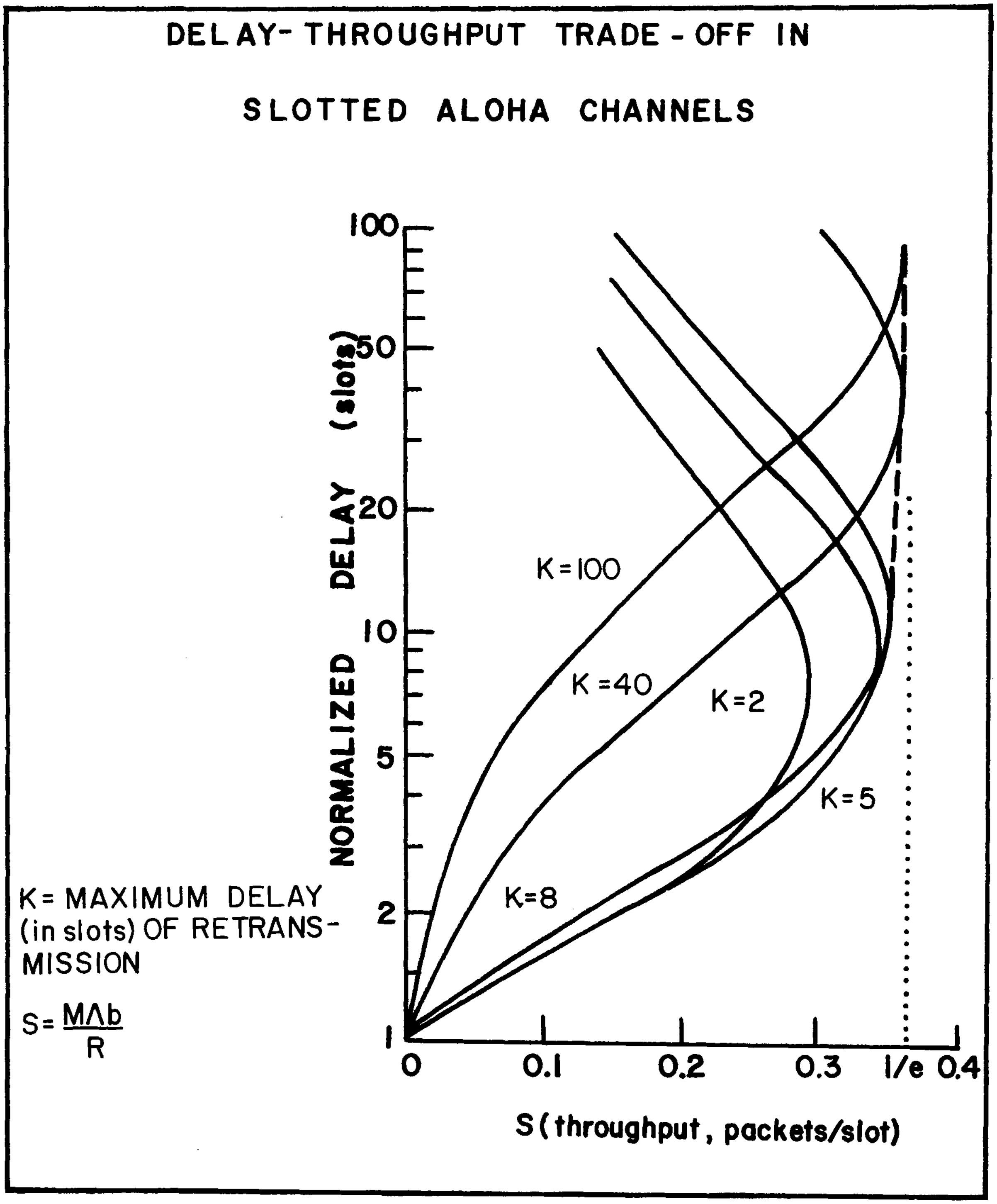
In the design of the network the operator of the system desires totally different parameters than does the end user. For example, the operator desires to maximize the use of his resource (in this case frequency spectrum) thus he would hope for an index of utilization as close to 100% as possible while the end user desires minimum delay. Since the network will have widely varying usage over the period of a day, the end user would hope that the network design was for the absolute peak but the operator would like to design for the average. The realistic design approach is to use statistical analysis of the probable demands placed on the network.

When the analysis is done properly, you will find that as net throughput increases the delay will also increase. Random access network curves can be developed to display this characteristic of the network. When the error rate increases and additional transmissions are required for correction both the net throughput decreases and delay increases.

The most complete analysis of a network is to compare net throughput versus delay at various retransmissions. One such example has been done for a slotted ALOHA Multiple Access channel. As can be seen by the curves, a knee exists over which the system will head toward a condition of complete lock up allowing no traffic to enter. Designs should be such that the network, at its statistical peak, will not exceed the values at the knee. If higher levels are required then you must change the access scheme to be more efficient. This, of course, carries a cost penalty.

SUMMARY

When entering the multiple access business network market consideration must be given to both the customer needs and the operator needs and trade offs must be made if the cost of service is to be kept competitive or attractive compared to existing resources. Remember, the most important parameter which is being sold is the subjective customer evaluation just as in the CATV customer.



DESIGN CONSIDERATIONS FOR A BANDWIDTH EFFICIENT
SPLIT-BAND TRUNK STATION

Joseph P. Preschutti
Director of Engineering

C-COR ELECTRONICS, INC.
State College, Pennsylvania

Abstract

Technical considerations for the design of a bandwidth efficient split-band trunk amplifier are discussed with some highlights on the choice of diplex filters and their effect on the performance of the amplifier. A comparison is given between guardband requirements for a standard 30/50 MHz sub-split amplifier and those for a 186/222 MHz split-band amplifier. Some practical considerations are outlined concerning the structure of the reverse amplifier module, and how the closed loop pilot controlled PIN Diode attenuator plays a major role in maintaining reverse system flatness. System performance specifications and test data are presented for a split-band gear with a reverse bandwidth of 5-186 MHz and forward bandwidth of 222-450 MHz.

1. Introduction

Mid-split systems of the mid-70's were straight-forward extensions of sub-split technologies that wasted and inefficiently used available bandwidth. Even so, interest in them remained. Today, a split-band amplifier with an upper frequency of 450 MHz and a spectrum allocated equally to forward and reverse systems is in demand. Design techniques for such a system are discussed in this paper. We will consider guardband characteristics, filter requirements, reverse level control, and reverse amplifier topology, and will describe a system with a 5-186 MHz/222-450 MHz spectrum and a guardband loss of only 6 channels.

2. Guardband Characteristics

When system designers plan broadband communications with equal bandwidth in both directions on a single cable, they must sacrifice a portion of the spectrum to stabilize amplifier operation.

The allowable spectrum consists of: the reverse passband, the guardband, and the forward passband. Any guardband is a loss of bandwidth, is useless for information transfer, and should be kept to a minimum.

Designers have recently increased the channel-carrying capabilities of broadband systems from 300 MHz to 330, 360, 400, and 450 MHz. This rise in frequency has been built on transistors with higher output power, more channel-carrying capability, and better performance. Generally, equipment designers have found sufficient challenge in modifying the supplemental circuits to guarantee operation at higher frequencies. In particular, gain adjust, slope adjust, level control circuitry, and RF chokes had to be re-worked. This design was difficult; considerable developmental time had to be allotted. Nevertheless, the theory was an extension of existing basic philosophies. We could not satisfactorily produce split-band amplifiers with 400 or 450 MHz upper frequencies by simple extensions of technology.

We began by comparing existing standard splits of the broadband spectrum (Figure 1). Of the four systems, the first is a standard sub-split system of the late 1960's and early 1970's. The reverse portion of the spectrum was 5-30 MHz while the forward was 50-300 MHz. A 20 MHz guardband centered at 40 MHz was standard.

The second bar illustrates a standard mid-split system in use around 1972; this one provided a more equal spectrum distribution with a larger reverse passband. These systems had a 5-108 MHz reverse passband with a 66 MHz guardband centered on 141 MHz and were designed to meet franchising requirments of the early 1970's. Since the recession of the mid 1970's, cable system operators had little use for split-band communication equipment until recently when

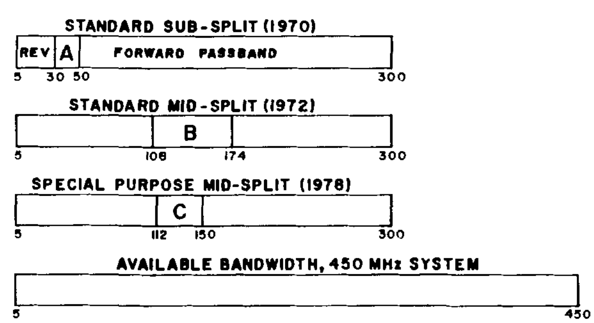


FIGURE 1
A COMPARISON OF EXISTING "STANDARD" SPLITS
OF BROADBAND SPECTRUM

franchising activities grew and broadband local area networks emerged. The only exception was a broadband telephone/cable television system attempted by a non-CATV company (see third bar of Figure 1) as a special-purpose mid-split and put into operation in 1978. Shown are reverse passband frequencies of 5-112 MHz, forward passband frequencies of 150-300 MHz, and a guardband of 112-150 MHz centered on 131 MHz. The technology was upgraded and the spectrum better utilized, but the system remained an exception.

The fourth bar of Figure 1 illustrates the available bandwidth in a 450 MHz system.

Filter quality is the key to successful split-band amplifiers. For this discussion, the filter types used in the three systems shown will be labeled as types A, B, and C. We will define filter quality in two terms: (1) the ratio of guardband width to the guardband center frequency, and (2) the ratio of the assigned guardband width to the total available bandwidth (see Table 1). Actually, the poorest filtering is in the sub-split systems where the guardband is a full 50 percent of the center frequency. However, this guardband width is only 7 percent of the available bandwidth and only 3.3 channels are lost. The mid-split 108/174 systems contained filters of similar quality, but merely shifted up in frequency to operate with a center frequency of 141 MHz. Here, we see considerable waste; the guardband occupied 22 percent of the available bandwidth; and a full 11 channels were lost. Type C filters designed around special-purpose amplifiers improved performance: 13 percent of the available bandwidth was used; 6.3 channels were lost; and the guardband occupied 29 percent of the center frequency. If we use these filters in an equal-split 450 MHz system, the results would be undesirable. Table 2 lists calculated performances for 450 MHz systems with guardband characteristics of the three previous 300 MHz split-band systems. From 9 to 16 channels are lost and from 13 to 25 percent of the available bandwidth is wasted for guardband use.

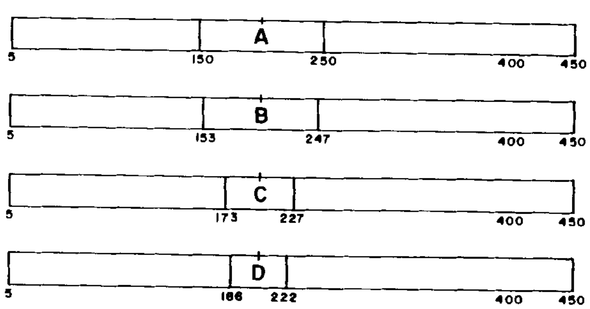


FIGURE 2
COMPARISON OF EXISTING TECHNOLOGIES WITH A MORE EFFICIENT SCHEME FOR 400/450 MHz "EQUAL SPLIT" SYSTEMS

Figure 2 illustrates 400 and 450 MHz systems using Type A, B, and C filters as well as the more efficient Type D, which only loses 6 channels. Naturally, Type D filters more efficiently use available bandwidth.

Filter Type	Bandpass, MHz	Guardband Efficiency % of Center Frequency	Guardband Efficiency % of Total Bandwidth	Lost Channels
A	5-30, 50-300	50	7	3.3
B	5-108, 174-300	47	22	11.0
C	5-112, 150-300	29	13	6.3

TABLE 1
Relative Performance of Existing Systems

3. Filter Characteristics

Crossover filter design is crucial to split-band equipment performance. Desirable characteristics include a flat passband, constant passband time delay, a sharp cutoff at transition, and a specific minimum attenuation of the stop-band. Two design factors are particularly important. The first is that sharp attenuation cutoffs and constant time delays are incompatible.[1] The second is that attenuation characteristics are the dominant requirement for stable trunk station operation.[2] Chebyshev filters offer minimum

Filter Type	Bandpass, MHz	Guardband Efficiency % of Center Frequency	Guardband Efficiency % of Total Bandwidth	Lost Channels
A	5-150, 250-450	50	23	17
B	5-153, 247-450	47	21	16
C	5-173, 227-450	29	12	9
D	5-186, 222-450	18	8	6

TABLE 2
450 MHz Split-Band Peformance
Using Several Filter Types

transition range for reaching a prescribed attenuation, and never provide a stopband attenuation less than the prescribed attenuation. We, therefore, chose Chebyshev filters. In the following sections, we discuss group delay characteristics and passband flatness.

3.1 Group Delay Characteristics

Chebyshev filter group delay depends on two variables. The first is filter complexity or number of filter branches. The second is cutoff frequency. Group delay will rise as filter complexity increases and will decrease as cutoff frequency rises. Group delay is more strongly dependent on cutoff frequency than it is on filter complexity, thus, Chebyshev filters for a split-band amplifier have less group delay than their sub-split counterparts. Figures 3 and 4 compare group delay of split-band filters with sub-band filters. (30 MHz sub-split, 112 MHz and 186 MHz split-band, low pass filters).

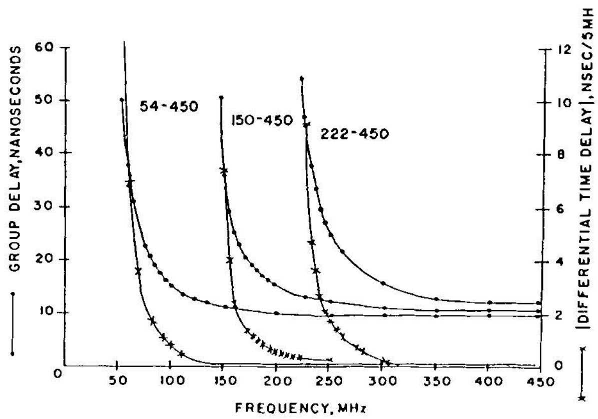


FIGURE 3
FORWARD BANDPASS GROUP DELAY AND DIFFERENTIAL GROUP DELAY FOR SEVERAL TRUNK STATIONS

3.2 Differential Group Delay

Although absolute group delay of higher frequency split-band filters is less than that of sub-split filters, the same is not necessarily true of the differential group delay (the change in group delay with the frequency change). Figures 3 and 4 plot change in group delay versus frequency change for 5 MHz increments throughout the reverse and forward passbands of the individual filter and also the trunk station. These numbers are compared to those for a typical sub-split trunk station.

3.3 Passband Flatness

Filter complexity and passband ripple define the sharpness of attenuation cutoffs in a Chebyshev filter. Attenuation transition regions can be sharpened by accepting a higher passband ripple with attendant higher band-edge roll off and then balancing this specification against lower filter complexity.

Naturally, we must add appropriate amplitude distortion equalizers on the reverse amplifier interstage if we want higher passband ripple. Figure 5 shows the response of an eight-branch Chebyshev diplexing filter with a 186/222 transition range.

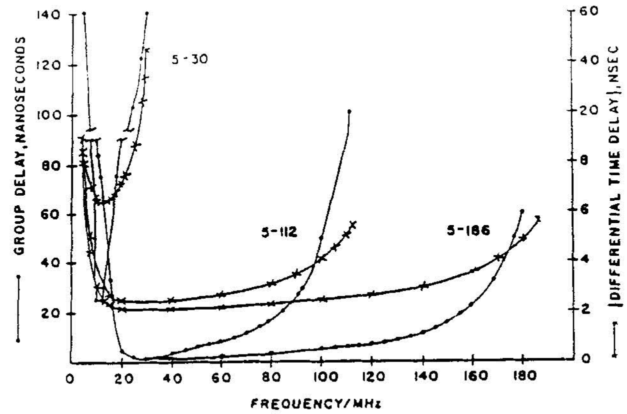


FIGURE 4
REVERSE BANDPASS GROUP DELAY AND DIFFERENTIAL GROUP DELAY FOR SEVERAL TRUNKS

3.4 Filter Alignment

Increased filter complexity imposes a price: More time will be required for alignment. It is also necessary to pay strict attention to filter stop-band attenuation, pole location, and crossover isolation, if we wish to provide adequate amplifier flatness and unconditional stability. Cross-over isolation of diplex filters

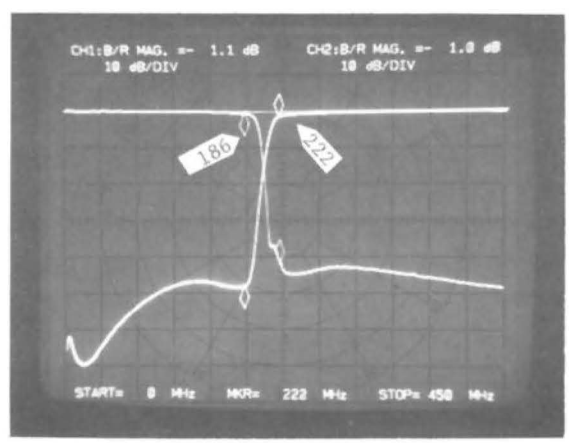


FIGURE 5
SWEPT RESPONSE OF 186/222 DIPLEX FILTER

in this application will degrade significantly when the combined port is unterminated, therefore, filters must be tested at a minimum crossover isolation specification under both terminated and unterminated conditions. Plug-in filters make this test easier; filter specialists can then align them in production tests, instead of trunk station alignment technicians.

4. Level Control

Open loop methods of reverse level control had proven practical in sub-split and split-band systems with reverse passband upper frequencies of 108 MHz and below. These circuits used a negative temperature coefficient thermistor as a series element in a bridged-T structure or as a series component in the RF signal path. But increased gain necessary in higher frequency split-band units and use of more channels significantly reduces dynamic range and mandates tight level control. We turned to PIN Diodes, which provide positive as well as negative resistance changes and are controllable by either closed or open loop methods. To control short systems with moderate temperature changes, we would choose a thermally driven PIN Diode circuit. In longer systems with wide temperature excursions, open loop is no longer satisfactory, and closed loop level control is the choice.

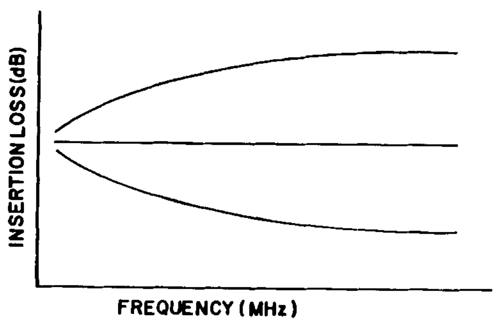


FIGURE 6
SLOPE COMPENSATED ATTENUATOR RESPONSE

Control of reverse system gain with closed loop method is not problem-free. If closed loop control is installed at every return trunk station, each extremity of a standard cable system would require a pilot signal generator. Then, the pilot on spur trunks would have to be trapped out so that combining pilots do not interfere or overload the system. Pilot signals must be kept to a minimum.

For this reason, a slope-compensated Automatic Level Control (ALC) using a single pilot is better than the dual-pilot approach of separate Automatic Gain Control (AGC) with separate Automatic Slope Control (ASC). Slope-compensated level control circuitry has characteristics similar to those in Figure 6. In this system, a

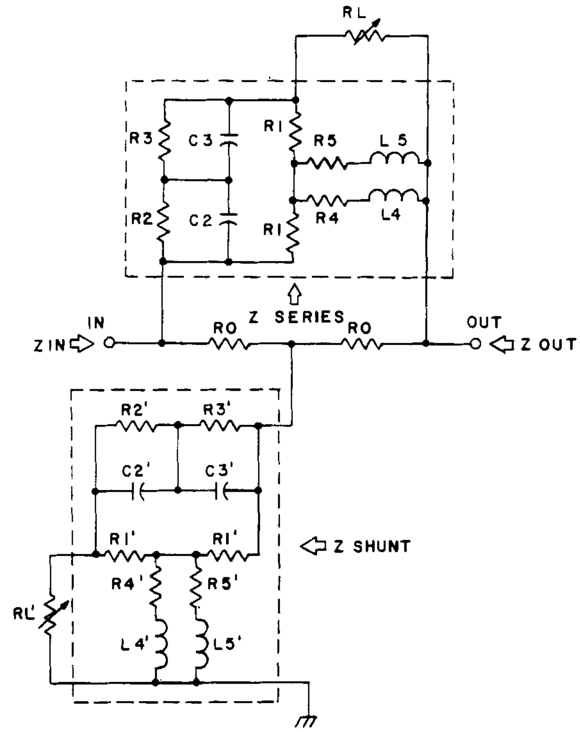


FIGURE 7
SCHEMATIC DIAGRAM OF A MULTIPLE OCTAVE GAIN CONTROL CIRCUIT.

single pilot operates at the high frequency, and the RF attenuator precisely and accurately compensates for cable loss changes. In this way, each trunk station requires only a single closed loop. Since system stability and transient response is a function of the number of control loops,[3] a slope-compensated approach to level control is strongly desirable. This design cuts in half the number of control loops.

The circuit (Figure 7) controls the RF attenuator with sufficient precision to produce slope-compensated ALC. Provided is a 5 1/2-octave response to cable attenuation changes.[4]

4.1 ALC System Summary

We built our level control system on thermally controlled PIN Diode RF attenuators added to all short spur trunks. For long cascades, thermally driven circuits predominate, but closed loop ALC reverse amplifiers are installed at every third amplifier (two out of three RA's are controlled thermally). We also specify pilot generators on main trunk lines; and call for pilot traps at intersections of pilot-controlled trunklines. (See Figure 8).

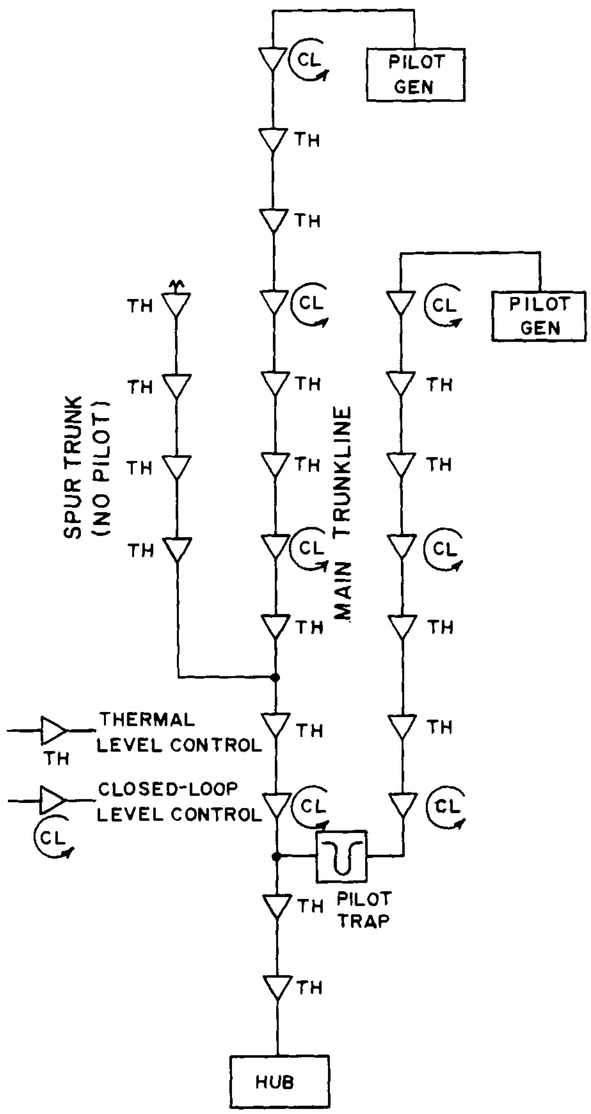


FIGURE 8

REVERSE SYSTEM LEVEL CONTROL

These figures assume 21 dB forward spacing at the highest frequency. Allowance for 8.5 dB flat loss between stations requires 16.4 dB reverse spacing. A rise in upper frequency of the forward section decreases reverse spacing; a rise in upper frequency of the return system increases return spacing.

5. The Reverse Amplifier

Reverse amplification in equal split-band 400 or 450 MHz systems is based on level control, loop gain requirements, trunk station reverse spacing, plus allowance for several controls, test points, and connectors normally associated with trunk amplifiers. We will discuss each and then combine all requirements into a logically optimized amplifier configuration.

BANDWIDTH, MHz		REVERSE SPACING, dB	
Reverse	Forward	Full Cable	With 8.5 dB Flat loss
5-30	50-300	6.0	12.1
5-30	50-450	4.9	11.4
5-108	150-300	12.1	15.7
5-108	150-450	10.4	14.3
5- 186	222-450	13.3	16.4

TABLE 3
Reverse Spacing For Various Systems

5.1 Loop Gain

The topology of a two-way broadband amplifier provides a feedback path that impresses an undesired signal on forward and return paths. Filtering must prevent passband gain perturbations and guardband oscillations through adequate loop gain (or loss). Adding all the available loop gains and losses determines amplifier loop gain. In the passband, a 40 dB loop loss is required to guarantee amplitude perturbations lower than 0.1 dB. In the guardband, at least 10 dB loop loss is necessary to prevent oscillations.

Two loops were considered in our trunk station design. Figure 9 illustrates trunk station topology used to calculate loop gains. Loop 1 includes the trunk forward amplifier and Reverse Amplifier (RA), plus trunk input and output filters. Loop 2 includes the trunk, bridger, reverse amplifier, trunk input filter, and bridger output filter. Assuming that trunk forward gains are 21, 16, and 36 dB respectively, trunk input and output filter stopband rejections of 40 dB each would provide adequate trunk

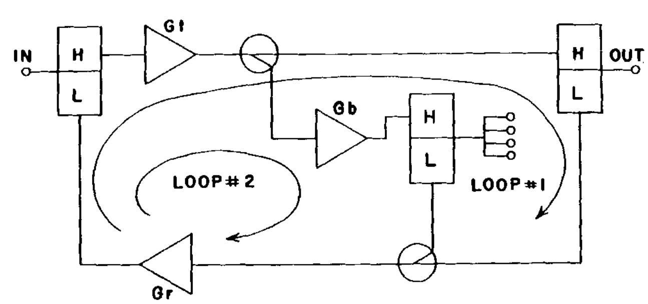


FIGURE 9

TRUNK TOPOLOGY FOR LOOP GAIN CALCULATIONS

flatness. Consequently, the Bridger Amplifier (BA) output filter would need about 50 dB stopband rejection to guarantee adequate trunkline passband flatness. This much rejection is difficult to achieve. Instead, we inserted another filter in the RA loop, and furnished 30 dB stopband rejection in both the RA and BA output filter.

5.2 Reverse Spacing

Several two-way system reverse spacings are shown in Table 3. Sub-split and split-band systems for both 300 and 450 MHz operation appear. The split-band systems show a 108/150 split, plus a 186/222 split for the 450 MHz system.

Trunk Input Filter	0.9
Trunk Output Filter	0.9
External Test Points (2)	0.7
Return Combiner	1.5
Slope Adjust Pot	2.0
Gain Adjust Pot	0.5
Lowpass Filter	0.5
Flatness Circuit	1.0
ALC with 2.5 dB Reserve	4.5
ALC Pick-off DC	0.5
Plug-in Cable EQ	1.0
Total Losses	14.0 dB

TABLE 4
Loss Budget for Trunk RA

These figures assume 21 dB forward spacing at the highest frequency. Allowance for 8.5 dB flat loss between stations requires 16.4 dB reverse spacing. A rise in upper frequency of the forward section decreases reverse spacing; a rise in upper frequency of the return system increases return spacing.

5.3 Reverse Amplifier Design

As noted previously, our reverse amplifier design includes a PIN Diode ALC circuit, a low-pass filter, and 16.7 dB spacing. The closed loop ALC uses a directional coupler on the RA output. Additionally, losses in trunk I/O filters, external test points, and controls for slope, reverse gain, etc. must be included. Table 4 lists them; they amount to 14 dB. Therefore, the total active gain block requirement of the RA is equal to 14 + 16.7 or 30.7 dB minimum.

This total gain is only slightly less than forward amplifier gain requirements and is best attained with two gain blocks (Figure 10). The flatness equalizer, slope, ALC, and filter are interstage; the plug-in cable equalizer and gain adjust are placed on the reverse amplifier output. The unit operates in a "constant input" mode and minimizes amplifier noise, while allowing the system designer to place splits in the trunkline without degrading reverse system performance.

6. Conclusion

Our design achieves efficient use of the available spectrum. Rather than degrade performance, the resultant increase in filter circuit complexity improves the system, since the guard-band center frequency moves upward. Through use of plug-in filters alignment becomes easier, amplifier stability remains high under mismatched termination conditions, and final trunk assemblies undergo easier production tests. Reverse amplifier complexity is increased to the point where reverse and forward amplifiers have nearly the same functional performance requirements.

References

[1]Zverev, A., Handbook for Filter Synthesis, John Wiley and Sons, Inc., 1967.

[2]Marron, H. B., Barnhart, A. W., "System Considerations in the Design of a Two-Way Transmissions System," NCTA Convention Transcripts, 1970.

[3]Chisolm, Eric, "Considerations on the Application of AGC/ASC Amplifiers in CATV Systems," IEEE Transactions on Cable Television, Volume CATV-1, No. 1, October 1976.

[4]Preschutti, J. P., Kyle, C. A., "A Five-Octave Level Control Circuit for Broadband Coaxial Cable Distribution Systems," IEEE Transactions on Broad casting, March 1983.

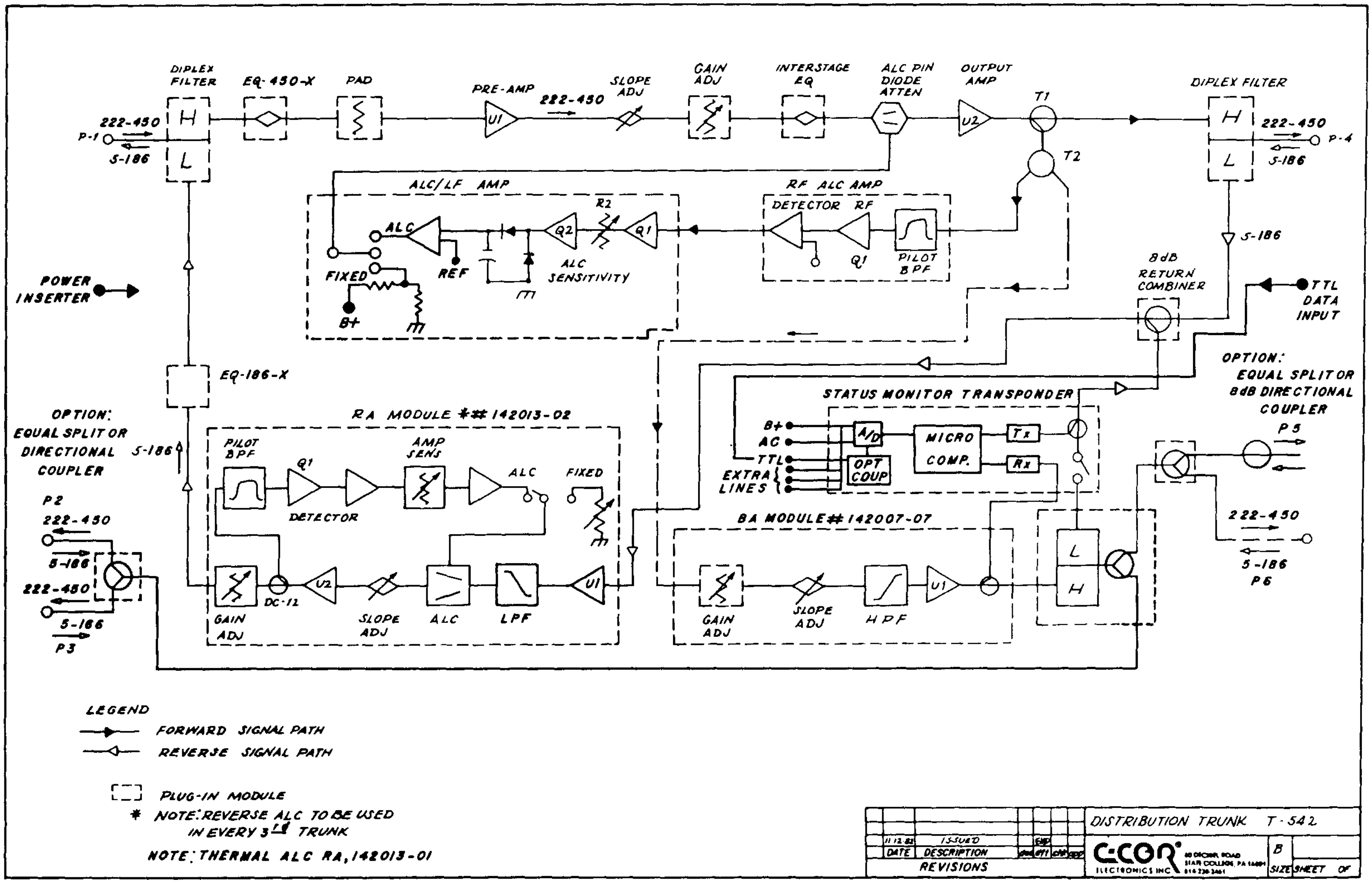

DIPLEX FILTER
EQ-450-X
PAD
PRE-AMP
222-450
SLOPE ADJ
GAIN ADJ
INTERSTAGE EQ
ALC PIN DIODE ATTEN
OUTPUT AMP
T1
T2
DIPLEX FILTER
222-450
P-1
5-186
H
L
U1
U2
222-450
P-4
5-186
ALC/LF AMP
RF ALC AMP
R2
ALC
Q2
Q1
DETECTOR
RF
FIXED
REF
ALC SENSITIVITY
PILOT BPF
B+
POWER INSERTER
5-186
8dB RETURN COMBINER
TTL DATA INPUT
EQ-186-X
OPTION: EQUAL SPLITOR 8dB DIRECTIONAL COUPLER
P5
RA MODULE *# 142013-02
STATUS MONITOR TRANSPONDER
OPTION: EQUAL SPLIT OR DIRECTIONAL COUPLER
5-186
PILOT BPF
AMP SENS
ALC
FIXED
DETECTOR
B+
AC
TTL
EXTRA LINES
A/D
OPT COUP
MICRO COMP.
Tx
Rx
P2
222-450
5-186
222-450
5-186
P3
BA MODULE# 142007-07
222-450
5-186
P6
GAIN ADJ
DC-12
SLOPE ADJ
ALC
LPF
GAIN ADJ
SLOPE ADJ
HPF
LEGEND
FORWARD SIGNAL PATH
REVERSE SIGNAL PATH
PLUG-IN MODULE
* NOTE: REVERSE ALC TO BE USED IN EVERY 3rd TRUNK
NOTE: THERMAL ALC RA, 142013-01
DISTRIBUTION TRUNK T-542
ISSUED
DATE
DESCRIPTION
REVISIONS
C-COR
ELECTRONICS INC
B
SIZE
SHEET OF

FIGURE 10

DESIGN CONSIDERATIONS FOR ENHANCEMENT OF A LARGE URBAN COAXIAL CABLE SYSTEM

WILLIAM E. EVANS

MANITOBA TELEPHONE SYSTEM

ABSTRACT

The large coaxial cable distribution system (CCDS) in Winnipeg, Manitoba, constructed as a 12 channel system in the late 1960s and now serving over 192,000 CATV subscribers, requires channel expansion for new television services and enhanced transmission performance to meet revised Department of Communications standards -- all within the context of providing a modern, multi-user, multi-service facility serving the broadband communication needs of various business, education and government users.

As the major communications common carrier in Manitoba, the Manitoba Telephone System (M.T.S.) has developed a plan for enhancement of the Winnipeg system based upon studies of alternative network configurations employing various communications technologies, such as Feedforward amplification, AM or FM Very High Capacity Microwave (VHCM), and analogue, digital or hybrid Fibre Optics.

Comparative study results forming the plan are presented along with details of the recommended network configuration. A purposeful commitment has been made to enhance the CCDS without adopting any distortion - masking techniques such as HRC or ICC phase-locking such that maximum flexibility is obtained to fully and flexibly use the network usefulness.

BACKGROUND

Two licenced CATV operators have provided service on a territorially - exclusive basis in Winnipeg with facilities constructed between 1967 and 1969. Both systems were designed for 220 MHz, 12 channel capacity using single ended amplification equipment and "Alucel" chemically expanded dielectric aluminum sheath cable, developed for CATV in 1964. These systems are now fully loaded with 12 television signals and face the need to add additional services such as national and regional pay television, specialized local programming, satellite delivered television programming and non-programming services such as security alarms. The larger of the two companies has identified a need for 17 additional television channels within the next 5 years, thereby producing an immediate need for enhancement of the existing facility to provide for midband and superband frequency spectrum usage.

As the provider of CCDS facilities in 34 communities throughout Manitoba, and a 279 mile coaxial cable Intercity Broadband Network (ICBN) linking 12 of those communities with Winnipeg, M.T.S. has been providing signal delivery for several non-CATV services on its coaxial cable facilities and is mandated to provide these functions in Winnipeg. PCM telephony, stereo music, Videotex, security alarms, closed circuit television, broadcast network television and data services have all been carried on provincial facilities and this same capability is now desired in Winnipeg.

PLANNING CONSIDERATIONS

The major consideration underlining the planning process was maximization of enhancement cost effectiveness through possible reuse of the existing cable and components, subject to their physical and electrical condition. To this end significant MTS-CATV operator joint testing was undertaken to evaluate the physical and electrical condition of existing active and passive devices from 5 to at least 300 MHz, with particular attention focussed on the shielding/RFI integrity of all components. Samples of the existing "Alucel" cable were submitted to an independent test laboratory for aging analysis of physical and electrical parameters.

Other major considerations in the planning process included the following:

a) Improved system reliability to reflect the carriage of essential services such as security alarms, and the increased customer expectations with respect to reliability of premium pay television services.

b) Significantly improved transmission performance at least meeting all requirements of the new Department of Communications (DOC)

Broadcast Procedure 23, Issue 2. This new specification significantly increases minimum subscriber drop levels, recognizing the mushrooming use of converters, and provides reference, for the first time, to Composite Triple Beat distortion.

c) Increased bandwidth and channel capacity to provide for maximum channel capacity within the constraint of cost-effectiveness, and with capability for future bi-directional operation, when required, through the addition of reverse amplifier modules and bridger switches.

d) Capability to provide an array of services (voice, video, data, facsimile, etc) and various modulation formats with maximum flexibility and usage of all frequency spectrum. The limitations and risks associated with employment of "heavy" phase-locking systems such as Harmonically Related Coherent (HRC) or Incrementally Coherent Carriers (ICC) were deemed unacceptable concepts.

e) The availability of status monitoring for system trunks is key to requisite system reliability and maintability in Winnipeg. Trunk amplifier stations are located in manholes on major traffic arteries. Trunk amplifier problems must necessarily be pinpointed accurately and quickly under these conditions. A paramount concern was the selection of a status monitoring system which could be integrated with the existing 256 amplifier ICBN monitor and, on an overall basis, integration of all CCDS alarms with the microwave radio, analogue and PCM carrier, satellite, switching and fibre optics alarms continuously monitored in the M.T.S. Provincial Central Alarm Centre in Winnipeg.

f) Maintainability by M.T.S. technicians supported by accurate and comprehensive records and effective communications is a major consideration.

g) The need for greatly improved RFI ingress protection to the entire CCDS, including subscriber drops, is inherent to the use of midband, superband and hyperband spectrum.

h) Given that the existing CCDS serves over 192,000 subscribers, with several signals being provided on a 24 hour basis, a vital planning consideration was logistics which would minimize service outages during the enhancement construction. While the defined logistics provide for outages only between 8:00 A.M. and 4:00 P.M., there may be surprises when construction starts.

NETWORK TOPOLOGY AND PERFORMANCE STANDARDS

The first step to defining the optimum enhanced CCDS configuration was to establish the worst case transmission performance standards for the overall facility. While the new Department of Communications BP-23, Issue 2, is a major input to this definition, M.T.S. CCDS specifications for rural broadband networks generally exceed the DOC standards and that same aspiration was embodied in the definition of standards for Winnipeg. Table 1 presents the overall worst case performance standards.

TABLE 1
WORST CASE WINNIPEG CCDS
TRANSMISSION PERFORMANCE STANDARDS

CARRIER TO NOISE RATIO (CNR)	43.0dB
CROSSMODULATION DISTORTION (35 CHANNELS PER NCTA 002-0267)	-53.0dB
SECOND ORDER DISTORTION	-67.0dB
WORST CASE COMPOSITE TRIPLE BEAT DISTORTION (CTB)	-55.0dB
HUM MODULATION (MEASURED PER DOC BP-23)	-50.0dB

An almost intuitive conclusion at the commencement of the planning process was that Winnipeg, by virtue of its population and physical size, would require a "hubbed" distribution plant with some type of supertrunk delivery of signals to each of the hubs from the master hubs near the CATV operator headends and studios. Given that assumption and the economic desirability of maximizing the size of each distribution hub area, it was possible to apportion the transmission performance specifications between the local (hub) distribution area and the supertrunk facility, with the latter requiring almost transparent performance in order to meet overall transmission specifications. Table 2 details the local distribution area worst case transmission performance specifications while Table 3 provides definition of these same parameters for the supertrunking system. The fundamental decision to avoid any service constraining distortion masking techniques, such as HRC or ICC phase-locking was embodied in the definition of transmission standards for all components of the CCDS.

TABLE 2 SUPERTRUNK DELIVERY SYSTEM PERFORMANCE SPECIFICATIONS	
CARRIER TO NOISE RATIO (CNR)	50.0dB
CROSSMODULATION DISTORTION (35 CHANNELS - PER NCTA 002-0267)	-64.0dB
SECOND ORDER DISTORTION	-77.0dB
WORST CASE COMPOSITE TRIPLE BEAT DISTORTION (CTB)	-71.0dB
HUM MODULATION (MEASURED PER DOC BP-23)	-53.0dB

TABLE 3 HUB DISTRIBUTION AREA WORST CASE TRANSMISSION PERFORMANCE SPECIFICATIONS	
CARRIER TO NOISE RATIO (CNR)	44.0dB
CROSSMODULATION DISTORTION (35 CHANNELS PER NCTA 002-0267)	-56.0dB
SECOND ORDER DISTORTION	-67.5dB
WORST CASE COMPOSITE TRIPLE BEAT DISTORTION (CTB)	-56.5dB
HUM MODULATION (MEASURED PER DOC BP-23)	-54.0dB

Physical sizing of the local distribution hub areas requires definition of the cable size and type to be used. Fortunately the results of the independent laboratory and joint MTS - CATV operator tests on the existing cable confirmed our desire to use as much of the existing coaxial cable as possible in the rebuild. (Our estimate of the replacement cost of the existing cable including all aerial, buried and underground plant is in the range of $10M to $15M). The disadvantage to the reuse is that because of its relatively high attenuation above 300 MHz (mainly due to the dielectric loss component), it is not cost-effectively used beyond a 300 MHz, 35 channel capability. These numbers, while trifling in the exciting world of US CATV franchising, are very respectable in the Canadian CATV market.

Given the local distribution area performance specifications and cable attenuations it was then possible to define an approximate geographical size for a local distribution area based upon the maximum allowable trunk and distribution cascades. Superimposition of this size on the city maps produce the conclusion that nine distribution hubs would be required for the enhanced facility. The CCDS hubs were not radically dissimilar to the MTS paired wire exchange areas, and nine central offices were natural choices as hub locations. Positive benefits to central office use include the availability of space for placement of modulators, processors, pilot carrier generators and associated equipment, emergency standby power generation and facility of interconnection with the paired wire telephone plant along with any existing carrier, fibre optics or radio trunk facilities.

While high-rise apartment blocks have been given secondary treatment in some CATV designs, with no overall consideration given to their effect on worst case transmission performance, it should be noted that the local distribution area specifications made provision for the inclusion of large Multiple Outlet Internal Distribution Systems (MOIDS) on the "tail end" of the distribution. Hence worst case transmission performance in a large high rise building is definitely considered within the bounds of the overall worst case subscriber transmission standards.

SUPERTRUNK TECHNOLOGY SELECTION

Selection of the optimum supertrunk configuration and technology was the most difficult exercise in the entire study because of the wide range of possible approaches and some significant pressure to integrate CATV and related services on new high capacity fibre optics trunk facilities being placed between several of the central offices. As a common carrier employing coaxial cable, fibre optics and various types of radio facilities throughout its service area, M.T.S. is very familiar with all technology options.

A. Very High Capacity Microwave (VHCM)

A number of options exist for the use of multi channel VHCM radio to provide, on a point to multi-point basis, CATV signal delivery to the hubs. The options considered were as follows:

i) 12 GHz AML in both high power and low power options.

ii) 15 GHz Double Sideband Amplitude Modulation (DSB AM)

iii) 15 GHz Frequency Modulation (FML).

iv) Reverse channel capability for both the 12 GHz and 15 GHz options was investigated using both 12 GHz and 15 GHz return options.

M.T.S. consideration of 15 GHz equipment was prompted by the close proximity to Winnipeg of a 12 GHz "digital radio corridor". The 12 GHz band is being reserved by the DOC within this corridor for future digital radio use by the TransCanada Telephone System.

In Canada the 12 GHz VHCM allocation provides for a total of 40 television channels, while only 32 channels are available in the 15 GHz VHCM band. Clearly the equipment required for 15 GHz operation is more expensive than the 12 GHz AML alternative.

B. Fibre Optics Transmission Systems (FOTS)

In early 1981 MTS issued an RFQ to a number of FOTS manufacturers for various alternative supertrunk configurations. Only two responses were received.

i) A U.S. manufacturer provided a quotation for an FDM-Frequency Modulation (FDM-FM) system using short wavelength fibre, with 5 channel per fibre loading and a maximum unrepeatered distance of 5km. This proposal would have required the use of intermediate repeaters.

ii) A Canadian manufacturer submitted two alternative proposals. Option 1 was for an FDM-FM system employing three video channels and associated audio per fibre, with an unrepeatered distance of 4km using shortwave length fibre. Option 2 was a High Order - Differential PCM (HO-DPCM) digital alternative with 2 channels per fibre each operating at 45 Mbps and four 6.3 Mb/s digital streams multiplexed onto a dedicated fibre with each 6.3 Mb/s stream carrying four audio channels. Using long wavelength fibre, an unrepeatered distance in excess of 10km was possible, thereby eliminating the need for repeaters. Future prospects of doubling the fibre capacity through Wave Division Multiplexing (WDM) and use of another "window" on the cable were also postulated.

iii) In early 1982 this manufacturer submitted another proposal using long wavelength fibre and Pulse Frequency Modulation (PFM) with WDM to provide 2 channels per fibre in an unrepeatered configuration.

iv) Another Canadian manufacturer, which has provided over 1700km of FOTS facilities for Saskatchewan's intercity CATV signal delivery network has been working closely with MTS in an attempt to provide cost competitive supertrunk facilities for Winnipeg. So far, the economics have not proven to be attractive due to the cost of terminal equipment.

All fibre optics proposals provided for a 40 channel capacity, nominally 35 forward and 5 reverse. The effects of repeater requirements are quite dramatic on the cost of the systems in that sophisticated remotely powered shelters with controlled environments are required.

While the analysis of comparative economics was based on equivalent loadings with standard NTSC vestigal sideband television channels, it was recognized that future utilization of the Winnipeg CCDS would involve transmission of FM broadcast signals, data signals with varying modulation formats and speeds, facsimile, pilot carriers, FM broadband video and other signals of varying "shapes and sizes". While modulators, demodulators and processors for coaxial cable transmission of these signals are generally available from a number of sources, and could likely be utilized with VHCM radio, there are no similar terminals available for FOTS usage. While this factor was not part of the economic analysis, it was recognized that FOTS cost, when adjusted to reflect the carriage of these ancillary and future services, would be progressively higher than for the other two alternatives. Provision of TV stereo audio will also be a problem with fibre and it is unlikely that any professional broadcaster would use the facility for television transmission at a 45 Mbps digital rate. (While professional standards for digital video are not yet fully established, postulated bit rates for quality signals exceed 300 Mbps).

C. Coaxial Cable Technology

It was clear from consideration of the specifications detailed in Table 3 that use of superlinear Feedforward amplifier technology would be required to facilitate coaxial cable supertrunking. Both 400 MHz, 52 channel and 300 MHz, 35 channel transmission options were considered. Various reverse transmission configurations were also studied employing sub low or mid split configurations.

Table 4 presents the comparative costs for the major technology options studied.

TABLE 4
COMPARATIVE COST RATIOS FOR MAJOR SUPERTRUNK TECHNOLOGY ALTERNATIVES

VHCM RADIO		
1) -	12 GHZ AML LOW POWER 32 CH FWD - 4 CH REV	1.87
2) -	12 GHZ AML HIGH POWER 32 CH FWD - 4 CH REV	2.15
3) -	15 GHZ DSB - AML * 30 CH FWD - 2 CH REV	1.92
4) -	15 GHZ FML * 30 CH FWD - 2 CH REV	2.48
FIBER OPTICS		
1) -	ANALOGUE FDM-FM II 40 CH CABLE - TERMINALS FOR 17 CHS	1.83
2) -	HYBRID PFM/WDM 40 CH CABLE - TERMINALS FOR 19 CH	3.33
3) -	DIGITAL HD-DPCM 40 CH CABLE - TERMINALS FOR 17 CH	10.32
FEEDFORWARD COAXIAL		
1) -	400 MHZ - 52 CHS FWD, 4 CH REV	1.05
2) -	300 MHZ - 35 CHS FWD, 4 CH REV	1.00
NOTES	* - MAXIMUM BAND CAPACITY IS 32 CH FWD AND REVERSE ** - COSTS FOR PROVISION OF CONTROLLED ENVIRONMENT REPEATER SITES NOT INCLUDED	

OBSERVATIONS

The recommendation that a 400 MHz Feedforward supertrunk system be employed was based on considerations other than just comparative cost. Future costs for expansion of the supertrunk capacity in either forward or reverse directions using coaxial cable show advantages over either of the two other technologies. All VHCM alternatives suffer from potential problems with respect to blockages, transmission deterioration during heavy storms and the need for federal licencing. At present VHCM carriage of television and FM broadcast signals is allowed by the DOC, but there is some question as to licencing requirements for data, facsimile, and other transmission services which will be required in the future. Bidirectional operation with VHCM would not be as easy as with either cable alternative.

VHCM, and particularly FOTS, raise concerns as to their flexibility with use of various modulation formats (AM, SSB, PSK, DFSK, QPSK, FM, etc) for differing types of telecommunication services.

Reliability and maintainability of the FOTS and VHCM alternatives was projected as being somewhat higher than for coaxial cable supertrunks, in spite of the inherent redundancy of the Feedforward amplification process. However, considering all relavent technical, economic and future factors the Feedforward coaxial cable supertrunking option was seen as the optimum selection.

With both Canadian FOTS manufacturers having their FOTS research and development facilities within 500 miles of Winnipeg, contact is maintained with both of these companies to closely monitor FOTS technology development. While we have seen fibre costs decrease dramatically (one supplier's prices decreased from 90¢ per fibre metre to 70¢ per fibre metre in less than one year) and have seen various modulation schemes proposed to simplify transmission and eliminate repeaters, it remains clear that it is terminal equipment costs which place FOTS supertrunking economics in a unfavourable position with respect to other alternatives at this time and for the foreseeable future. That there will have to be major improvements made in terminal cost effectiveness in this technology before it will be competitive.

PLANNING STUDY CONCLUSIONS

As a result of the technical and economic analysis of the technology alternatives, the independent laboratory analysis, and the joint MTS - CATV operator field tests, the following conclusions emerged for the enhancement plan.

(a) The existing "Alucel" chemically-expanded dielectric cable would be used for area distribution and hub area trunking wherever possible.

(b) New area trunks, and extensions to existing trunks, would employ third generation Gas Injected Dielectric (GID) cables.

(c) The supertrunks would employ 19.0mm Fused Disc coaxial cable.

(d) Supertrunk facilities would be standby powered using the Uninterruptable Power Supplies (UPS) developed for use with the provincial ICBN. Standby powering of area trunk and distribution was not seen as requisite or economic at this time, largely in view of the very substantial battery requirements necessitated by the severe winter climate in Manitoba.

(e) A distributed-intelligence, multi microprocessor based status monitoring system employing Intel "multi-bus" technology is being developed for the Winnipeg CCDS such that it will be integrated with the existing ICBN status monitoring system and the MTS provincial alarm centre.

(f) Replacement of all passive devices and splices with devices employing radiation sleeve connectors.

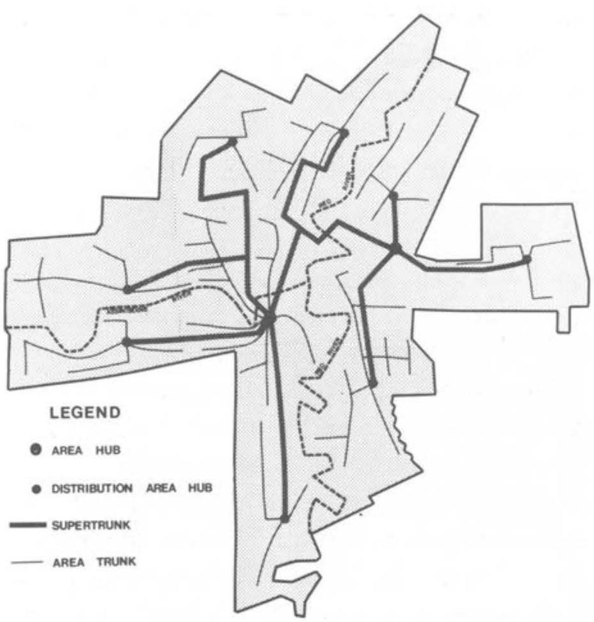
(g) Reconnectorization of all subscriber drop cables using connectors with extended integral ferrules and deep penetration mandrels.

(h) Use of 300 MHz push-pull amplifier technology on area trunks and distribution, with AGC employed in the distribution on some long cascades. Reverse transmission capability is provided for future implementation through module and bridger switch additions when required.

(i) Use of 400 MHz Feedforward amplifier supertrunks equipped with sub-low reverse transmission modules, upgradeable to mid-split as future service requirements dictate.

Figure 1 gives an overall view of the final network topology.

FIGURE 1



Those contemplating the construction of a new system in a city of similar size might ask what changes to the topology would result from a commitment to provide 400 MHz, 52 channel capacity, while still maintaining freedom from phase-lock techniques and the use of multi-channel microwave. These requirements would dictate the use of Feedforward for supertrunking, area trunking, bridgers and probably most of the distribution cascades. Replacement of Feedforward coaxial cable supertrunks with VHCM microwave would not change these requirements significantly since as the system-limiting Composite Triple Beat distortion problem is almost totally resident in the distribution, bridging and area trunks.

ACKNOWLEDGEMENTS

The author is very grateful to Messrs. P.H. Engbrecht, J.C. Rohne, E.S. Walker, T.M. Alldread, J.A. Anderson, K.G. Babb, W.R. Shields and G.J.M. Normandeau for their efforts on the planning studies and assistance in preparation of this paper.

BIBLIOGRAPHY

(1) W.E. Evans, J.C. Rohne, E.S. Walker "An Intercity Broadband Network for Rural Manitoba", IEEE Transactions on Cable Television, October 1978

(2) E.S. Walker, T.M. Alldread "An Advanced Micro Processor Based CATV Status Monitor System", IEEE Transactions on Cable Television, July 1979.

(3) M.F. Jeffers "Technical Considerations for Operating Systems Expanded to Fifty or More Television Channels", IEEE Transactions on Cable Television, January 1980

(4) A.S. Taylor "The Hidden Costs of 400 MHz", IEEE Transaction On Cable Television, January 1980

(5) I. Switzer "Extended Bandwidth Cable Communication Systems", IEEE Transactions on Cable Television, January 1980

(6) R.M. Blumenkranz "A Microprocessor Monitored Feed-forward Super Trunk CATV Amplifier", IEEE Transaction on Cable Television, July 1980.

(7) W.E. Evans, J.C. Rohne "An Intercity Coaxial Cable Electronics Highway" IEEE Transactions on Cable Television, April 1979.

EARTH STATION DESIGN CONSIDERATIONS
FOR 2° C BAND SATELLITE SPACING

Norman Weinhouse

HUGHES COMMUNICATIONS, INC.

INTRODUCTION

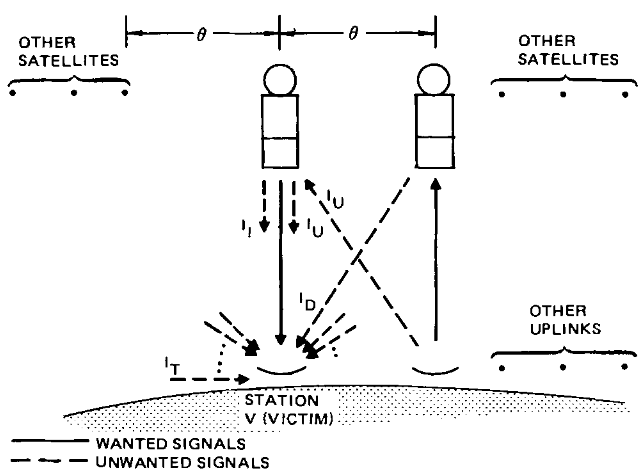
The Federal Communication Commission "Open Skies" policy, which allowed technically and financially qualified entities to launch and operate domestic satellite facilities, has been a great success. Benefits to virtually all elements of the telecommunications industry and ultimately to the public have been derived. The policy has certainly been a positive factor in the CATV industry, and perhaps a major technological catalyst in its development.

The geostationary orbital arc, that imaginary line 22,300 miles above the earth's equator, is a finite resource. It has been 2-1/2 years since the Commission made its last C-band authorization[1]. That round of authorizations established a constellation of C-band satellites with 4° spacing. Most of those satellites are currently in orbit, some will be launched this year, and the balance next year. The applications kept coming to the Commission, and in November 1981 a Notice of Inquiry and Proposed Rulemaking[2] was issued relating to the implementation of a 2° spacing plan for both C-band and Ku-band satellites. The rulemaking involved establishment of new technical standards for earth station antennas relating to the gain and cross polarization isolation in the close-in sidelobes. Comments were made by 37 entities. At last year's NCTA convention this author was moderator of a session on this subject and gave a detailed report on the comments received by the Commission. At the time this paper is written, the FCC has still not completed its deliberations in this docket. Regardless of the exact determination, CATV existing facilities will be adversely affected. The degree to which they will be affected and when this will take place is speculative, and any analysis ultimately involves a subjective evaluation of an acceptable level of interference.

This paper will outline the ground terminal receive only design considerations for 2° spacing of C-band satellites to permit antenna manufacturers to assess and respond to the changing marketplace. By the same token, operators should be aware that their facilities will probably need to be upgraded.

CARRIER TO INTERFERENCE RATIO

Consider the complex situation of the receiver of station V in Figure 1. It must contend with interference inside its passband from terrestrial sources and its own satellite's internal sources. It also is bombarded with interference from other satellites and from uplink stations transmitting to other satellites. The receiver's only asset to counter this interference is



$$C/I_{TOT} = (C/I)_T \oplus (C/I)_I \oplus (C/I)_D \oplus (C/I)_U$$

$$(C/I)_U = EIRP_{ES} - \sum_{i=1}^{N} \oplus \left[EIRP_i - (G_i - G_{\theta_i}) + F_i + P_i\right]$$

$$(C/I)_D = EIRP_{SAT} + G_{ES} - \sum_{i=1}^{N} \oplus \left[EIRP_i + G_{ES}(\theta_i) + F_i + P_i\right]$$

FIGURE 1. INTERFERENCE MODEL

its antenna off-axis discrimination characteristics. If antennas had no sidelobes, no problem would exist; it would be necessary only that satellites other than the desired one be spaced outside the main beam or, conversely, that the beam of the earth station antenna be narrower than the spacing between satellites. Of course, the earth station's antenna must have cross polarization isolation in the main beam because cross polarized signals are coming in from the desired satellite. We live in an imperfect world, however, in which antennas have sidelobes. It is sidelobe characteristics which will be discussed here.

Table 1 quantifies the interference situation. The values assumed for $(C/I)_T$ (terrestrial), $(C/I)_I$ (internal) and $(C/I)_U$ (uplink) are reasonable, assuming the station is properly protected from terrestrial sources and that suitable uplinks are accessing other satellites. In the $(C/I)_{TOT}$ column two figures are used. The first figure, 18dB, is generally accepted as adequate for CATV viewing. Some conservative members of the CATV industry, however, would like to design for higher values. The $(C/I)_D$ (downlink) column is the result of power addition and represents design criteria for the receiving antenna, based on each value of $(C/I)_{TOT}$.

TABLE 1

$(C/I)_{TOT}$ dB	$(C/I)_T$ dB	$(C/I)_I$ dB	$(C/I)_U$ dB	$(C/I)_D$ dB
18	25	26	27	19.9
20	25	26	27	23.6

A conservative approach would not depend on cross-polarization isolation from other satellites, because this factor is extremely weather dependent. Modest rainfall and uneven snow buildup on the antenna will destroy the off axis cross-polarization discrimination, thereby affecting the reliability of service. Any benefit to be derived from adjacent satellite cross-polarization should be regarded as margin in the overall system design.

Another important consideration is that the space constellation is not homogeneous, and it is not feasible to attempt to produce this condition by regulating EIRP. The earth station antenna design should take into account at least a 3 dB difference between the desired satellite EIRP and that of adjacent other satellites.

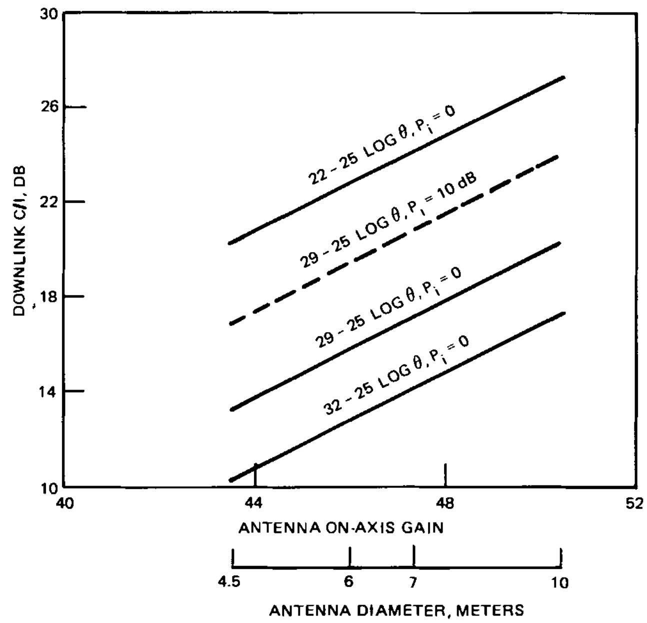


FIGURE 2. DOWNLINK C/I VERSUS ANTENNA GAIN FOR VARIOUS SIDELOBE ENVELOPES (2° SPACING)

The formula for downlink C/I can now be expressed as:

$$(C/I)_D = EIRP_{SAT} + G_{ES} - \sum_{i=1}^{N} \oplus \left[(EIRP_{SAT} + 3) + G_{ES}(\theta)_i + F_i \right] dB$$

Assuming F_i to be -6.5 dB, which is a worst case situation in which FM-TV is in all adjacent cross-pol channels, the curves of Figure 2 can be computed. It is obvious that the desired C/I can be obtained by using either a large antenna (high gain) or a smaller antenna with lower sidelobes. The lowest-cost choice, of course, is the latter.

SIDELOBES

Figure 3 shows the sidelobe contributors in a typical cassegrain antenna. A focal point antenna contains all these factors except for subreflector spillover. Both spillover contributors affect only the performance far-off the boresight. The other contributors affect close-in as well as far-out performance. Quantization of these contributors is within control of the antenna designer and the manufacturing process used.

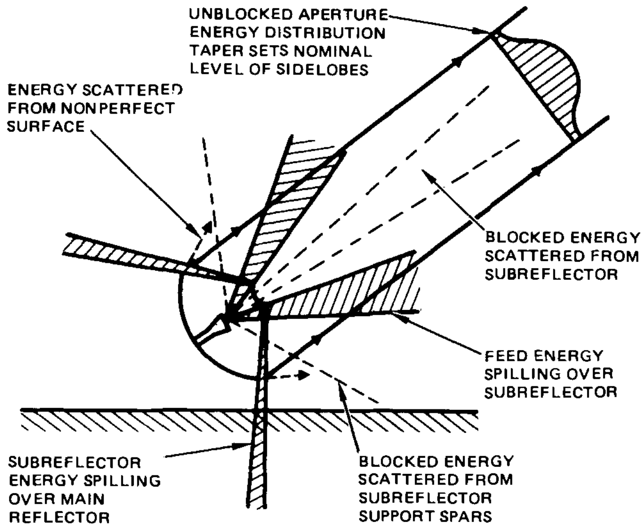


FIGURE 3. ANTENNA SIDELOBE CONTRIBUTORS

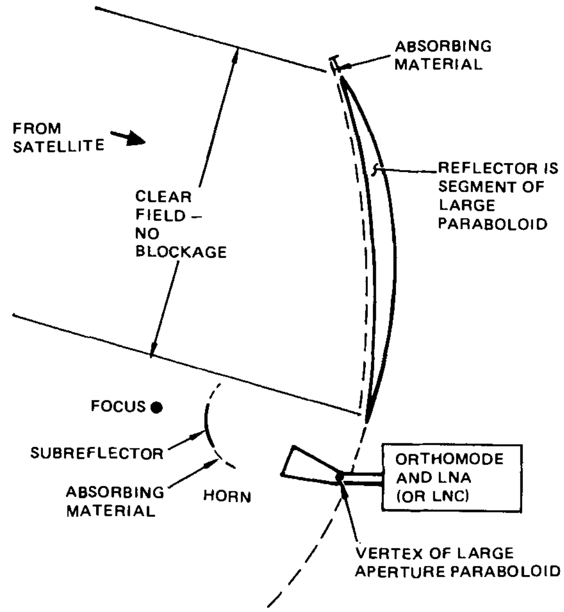


FIGURE 4. GEOMETRY OF OFFSET FEED, LOW SIDELOBE ANTENNA

Several approaches are available to antenna designers. The FCC lists the following options in the analysis section of the referenced rule-making proceeding[2]:

1. A reduction of antenna illumination lowers the main-beam gain slightly, but reduces the sidelobes considerably. The effectiveness of this technique increases with antenna diameter.

2. Corrugated antenna feeds have lower sidelobe levels.

3. Design practices can minimize re-radiation from secondary antenna reflector supports and antenna edges.

4. Off-set feed antenna designs reduce the effects caused by subreflectors and supports.

5. Horn antennas have lower sidelobes than parabolic dishes.

6. Improved manufacturing tolerances can reduce sidelobe levels resulting from the effects of antenna reflector surface errors.

In this author's opinion, all these options have merit and can achieve the performance level suggested by the FCC (i.e., envelope of 29-25 log θ). With the more conservative approach given above, however, small aperture antennas will need a better sidelobe envelope for an environment of 2° spacing. It is doubtful that any one of the approaches suggested by the FCC, if taken alone, will produce the desired result for antennas with a diameter of less than 10 meters at C-band.

For antennas less than 10 meters in diameter, an offset feed geometry is recommended. The offset feed provides a good deal of flexibility in the compromise between on-axis gain and sidelobe levels (aperture illumination) because there is no aperture blockage. In addition, a dual reflector design, either cassegrain or gregorian, is recommended so that the main beam cross-polarization isolation can be maintained at a high level. Figure 4 shows the geometry of a typical offset feed antenna. This type of antenna has been described in a number of technical articles[3,4].

CONCLUSIONS

To cope with a C-band satellite constellation with 2° spacing, CATV receiving antennas will need improved sidelobe performance. A conservative system approach indicates that the FCC proposed performance standard will not be adequate for small aperture antennas, especially with nonhomogeneous space segment. An offset feed antenna configuration can be implemented at reasonable cost to produce the desired sidelobe performance with an aperture of 4.5 meters diameter or less.

FOOTNOTES

1. Orbit Deployment Plan, 84 FCC 2d 584 (1981).

2. Licensing of Space Stations in the Domestic Fixed-Satellite Service and Related Revisions of Part 25 of the Rules and Regulations, FCC 81-466, released 18 November 1981, Docket No. 81-704.

3. Japan, An Example of an Antenna Configuration for Efficient Utilization of the Geostationary Satellite Orbit, CCIR Report 390-3, 453-2.

4. B.H. Burdine and E.J. Wilkinson, "A Low Sidelobe Earth Station Antenna for the 4/6 GHz Band," Microwave Journal, November 1980.

EFFECTIVENESS OF STATIC SCRAMBLING VS DYNAMIC SCRAMBLING SYSTEMS A CLASSIFICATION METHOD

MICHAEL T. HAYASHI

PIONEER COMMUNICATIONS OF AMERICA, INC.
COLUMBUS, OHIO

ABSTRACT

Various scrambling systems have been introduced to the market place as a possible solution to the industry wide problem of theft of service. The effectiveness of scrambling is often a very confusing and difficult factor to determine. Classification of the various scrambling systems available today yeilds two basic forms -- static and dynamic. The effectiveness of the two varies depending upon the key signal and reference signal used in the descrambling process. Majority of scrambling systems are designed by slightly deviating from NTSC TV standards. Thus, from its initial design concept, these scrambling systems are vulnerable to pirate designs. Complete video encryption may certainly be the solution. However, the associated price is not affordable today. What compromises can be made to design an affordable ultimate scrambling system?

INTRODUCTION

Theft of service is a major concern for the entire cable industry. This concern has increased in proportion to the increase in value and quantity of products to be "stolen." Various methods of service protection have evolved in recent years, with more expected to surface. TV signal scrambling (as we all know) is one of the techniques used to deter potential theft of TV signals. It should be made clear that scrambling is merely a protective mechanism for premium TV pictures. TV signal scrambling is not a means to avoid other forms of service theft to which our industry is exposed. The operator will still need to contend with theft of hardware, hardware tampering and security of operation (installers), etc. However, with the considerable increase in consumer value of cable programming and the number of channels offered, cable signals must be protected.

This paper discusses specific aspects of all forms of TV scrambling/signal encoding. The flood of various scrambling methods being introduced -- RF vs baseband, sine wave sync vs gated sync, jamming, dynamic switching, random rate, encrypted scrambling, just to name a few -- can be very confusing, especially when one is attempting to judge the relative security provided by each method.

DEFINITION OF TV SIGNAL SCRAMBLING

From a technical perspective, a scrambling system has two purposes -- to prevent reception by "normal" television and to be capable of restoring the scrambled signal for reception by "normal" television. In the United States, television sets are designed to National Television System Committee (NTSC) standards. Therefore, deviation from the NTSC standard processing of the signal in most cases will accomplish scrambling. However, the term, "normal TV," provides its own share of confusion due to the technical advances in television receivers to accommodate such relatively unstable signal sources as home VTR's and video game machines. In addition there is cable ready, component TV, and digital TV. Scrambling methods, therefore, must be carefully chosen to be sure they introduce a scrambling factor beyond what the TV reciever may consider a tolerable variance from its standard (NTSC).

The subjective effectiveness of scrambling is another factor to consider when selecting a scrambling method. The tolerance level for a scrambled picture of someone recieving that picture "free" may be very high. Therefore, the scrambling level should be sufficient to render any TV picture received without a decoder subjectively unacceptable to an audience group, even if they are recieving it "free." Depending on program content, what one wants to see or hear will vary, making it very difficult to determine a guideline as what is acceptable scrambling in all cases.

The final factor in determining secure scrambling is the level of difficulty required to defeat the scrambling method. The level of difficulty is tied directly to the cost of preventing defeat. Obviously, the ideal is authorized descrambler would have the highest difficulty level possible at the lowest possible cost.

STATIC VS DYNAMIC SCRAMBLING SYSTEMS

Based upon method of application, TV signal scrambling or encoding can largely be classified into two major categories: static scrambling and dynamic scrambling.

Static scrambling processes the signal in a constant and predictable manner with respect to time. Dynamic scrambling, on the other hand, takes away the element of predictability within the scrambled signal itself. Dynamic scrambling is thus more secure in most cases than static scrambling forms because it introduces an added element to be decoded -- time.

In addition to the actual scrambling itself, all active scrambling systems may incorporate one or two types of information for proper descrambling. A reference signal may be required to re-establish proper descrambling levels and/or timing. A key signal may be used to determine when and what type of encoding method may be taking place. In certain instances, the same signal may carry both two types of information creating a situation where the signal function can be easily misinterpreted or misunderstood.

Obviously, knowing the built-in reference/key signals is vital to decoding dynamic scrambling systems. This knowledge is not absolutely essential in static systems since reference can be recreated once the scrambling method is determined. Thus, in a static system, a potential pirate designer has a choice of generating his own reference signal or utilizing the reference signal available within the scrambling system; whereas, in a dynamic scrambling system, the pirate designer is forced to retrieve the reference signal to descramble, restricting his choice of approach.

One variation of the static system is the combining of static form of scrambling with a varying reference signal. This method would seem to provide added security due to its protected reference signal, but it is essentially still weak due to the fact that the actual scrambling mechanism is static. Dynamic scrambling with an unprotected reference signal is likewise not absolutely secure once the relationship between the reference signal and the scrambled picture is established.

This brings us to the combination of dynamic scrambling and protected reference/key signal. To steal service, a pirate designer will now have to determine how the reference/key signal is protected. This type of scrambling system depends greatly on two factors -- the "dynamic"-ness of the scrambling method itself and the level of reference/key signal protection. Dynamic scrambling, as we determined earlier, depends on the level of upredictability with respect to timing of the scrambling itself. Perhaps it would be more understandable to say that the larger the number of possible scrambling patterns or modes, the more unpredictable the system will be. No matter how dynamic the signal, the scrambling system itself loses its effectiveness against pirate designers if the reference signal is easily decoded. Therefore, analogue protection of reference signal with its limited number of variations is not as desirable as digital encoding which potentially has a significantly greater number of combinations.

In order to better understand the differences in static vs dynamic scrambling and the relationship to reference/key signal, let us look at a generic example.

A TV picture consists of synchronization pulses required to center the picture onto its CRT. Elimination of these pulses theoretically causes scrambling by preventing the TV set from stabiling the picture. Sine-wave sync suppression systems and gated sync suppression systems are all designed to achieve this effect. For the sake of illustration, let us use sync suppression for our exercise design of a secure scrambling system.

The first form we might use is constant video sync suppression with a fixed reference signal AM modulated on the aural carrier. Refering to our definition, this method is static scrambling in its most basic form. The second step we may take is to vary the reference signal timing so it does not corelate to the actual sync suppression timing. Still, the scrambling is a constant video sync suppression which is static. It is therefore, vulnerable to pirate design by bypassing the reference signal all together. Understanding that even a varying reference signal does not adequately protect a scramble picture because it can be bypassed, we can probably safely conclude that all forms of static scrambling offer approximately the same amount of protection from pirate designs.

Dynamic scrambling when applied to sync suppression offers a wide variety of scrambling combinations. Alteration of the depth of sync suppression, variation of the suppression frequency in a manner that makes it a harmonic of the sync frequency, random sync suppression by frame and random sync suppression by line, all have the potential to qualify as dynamic scrambling if they meet the criteria of unpredictability with respect to time. These methods are in many cases an improvement over static methods. However, even here an unprotected reference signal makes dynamic scrambling just as vulnerable to theft as static systems. For example, if the timing information for random sync suppression were directly AM modulated on the aural carrier, all the pirate would have to do is reapply that signal to the scrambled video. The timing reference for random sync suppression can be digitized. A digital data word corresponding to suppressed or not suppressed is an added layer of protection requiring data detection and decoding. Although considerably more secure than our starting point of basic static sync suppression, there is still a vulnerability factor in the "dynamic"-ness of the scrambling method and the decoding of the reference signal.

ENCRYPTION DEFINITION AND POTENTIAL

A constant "game" is currently being played in the cable industry with regard to theft of signal. One day a very powerful scrambling method is announced. The next day it is defeated. The cable operator wants a secure signal, but cannot relay on claims made because pirate designers are keeping up with the pace of vendor technology. In an environment like this, encryption of signal is an ideal form of signal protection. Encryption technology assumes, given time, all codes, will eventually be broken. This is philosophy recognizes the present scrambling games played between the pirate designers and the cable industry. The difference is that most encryption systems allow an astronomical number of variations for possible key codes to the encrypted signal. An anology can be made to a door lock and its key. The mechanism of a door lock is common knowledge; however, if you do not have the key that fits, you will not be able to open that door lock. Suppose you finally duplicated the key by carefully studying the door lock, but that lock can be easily changed to let a different key work. . . . The door lock is like a scrambling method which can be made public knowledge because there are a billion variations of possible keys and the internal components of the lock are continually changing.

The advantages of scrambling systems using encryption are numerous. Descrambling devices could be sold directly to the subscriber without fear that they would be used as a potential theft tool. The majority of today's pirate devices are add-on descrambling bases made up of actual manufacturers' products which have been either stolen or sold indirectly to the pirate houses. If the descrambler can be properly activated only by entering a unique key code which will vary from time and which is given only to paying subscribers, problems associated with the distribution of descramblers can potentially be solved.

The benefits of descrambler standardization as a result of encryption, coupled with TV standardization, may eventually allow the cable operator to eliminate a significant amount of hardware investment in the home. Of course, the operational aspect of this possibility will have to be carefully studied. With cable penetration over the 35% mark, making the descrambler a direct consumer product is not an unreasonable proposal. Encryption algorithm must be chosen so that it allows viewing only by a valid paying subscriber. The problem of paying subscribers disclosing encryption keys must be resolved both in operational system design and hardware design. A customized unique decrypting number for specific subscriber hardware may exist on a monthly billing basis, service basis, or even per program basis.

Now that we have seen a some idea of what encryption can possibly do for us, we can explore what is to be encrypted. Let us continue the evolution of the product design we started in our earlier appraisal of static scrambling. Our next step will be to encrypt the key signal associated with a dynamic scrambling method. If random sync suppression within a TV picture frame were the dynamic scrambling method chosen, the suppressed or not-suppressed timing is encrypted. Detection of digital key signal cannot be used to directly decipher the random occurrences of sync suppression unless the algorithm and decryption code are determined.

This form scrambling is particularily powerful since a decryption code may have a million possible combinations in addition to the dynamically changing patterns of sync suppression. In addition to the signal security of dynamic scrambling, encryption of key signal now provides opportunity to design systems which could safely allow standalone descramblers. The descramblers in this type of system could be made unique relative to each other. Changes in algorithm factors from systems to system will automatically resolve the cross system theft problem.

The last step in this design exercise is to encrypt video content. So long as the scrambled information does not alter basic video information, all non-encrypted video scrambling methods carry the possibility of being defeated. A variety of methods exists for encrypting video. These methods range from a simple a simple line randomization to time randomization of picture content, just short of digital video transmission.

STATE OF TECHNOLOGY

A true encrypted scrambling system is currently only available to the satellite industry due to the cost associated with encrypted scrambling. Satellite descramblers can afford to carry a price tag of several thousand dollars. Scramble/ descramble systems for the CATV industry certainly will have to maintain current price levels, eliminating direct application of satellite descramblers in the home. However, with the advent of charge coupled device (CCD) technology, digital television technology and advances in other semiconductor technology, the cost associated with complicated video processing can significantly drop, and true encrypted scrambling may some day be a viable technique for CATV signal protection.

Probably the most advanced form of scrambling systems available today within a competitive price range are the hybrid systems which use dynamic scrambling and encrypted digital key codes. Certainly not expected to last forever undefeated as long as these systems are designed within the realm of NTSC standards. Dynamic scrambling methods all maintain the basic rules set forth in the NTSC standards. For example, the deviation from NTSC standards of sync suppression and video inversion are relatively very minor. Significant deviation is not possible from the reasons associated to cost of product and ease of design. And for the very same reason, the vulnerability to pirate designers remains.

CONCLUSION

Scrambling system as they exist today are certainly not the ultimate solution to theft of service. The degree of difficulty in descrambling may vary from method to method; however, no method available to the industry can guarantee it will never be defeated. Some new TV sets are designed to be capable of tuning to semi-scrambled signals. Certain TV sets, for example, can automatically descramble static sync suppression. Less simple but a likely possibility for defeating all regular scrambling systems including dynamic scrambling, are other modification method using the TV set as a descrambling tool. Such modifications are possible since descramblers, to be price competitive, are designed with components commonly found insider the TV set itself.

Furthermore, many scrambling systems do not take into consideration other factors which impact theft of service. A system may develop a very powerful secure scrambling method which is ultimately defeated because it is housed in a descrambler device which lacks proper hardware security.

Theft of service can be greatly reduced by eliminating incentives that induce theft. Hardware construction of descrambler units should be secure to protect the internal components. Mechanical locks, access traps, custom chips, etc., should be used. Even the all outdoor delivery methods base signal security on lack of incentive for a potential thief to climb a pole or break a pad lock to steal service. While secure scrambling is certainly desireable, it is often overemphasized in the total theft of service scene. Strong scrambling methods are needed but equal attention must be placed on the operational aspect of the design so that the incentive to steal is eliminated.

Similarly, scrambling methods should minimize theft incentives. However, all video scrambling methods available to the cable industry today are only minor deviations from the NTSC standards, and thus, remain vulnerable to pirate designs. The issue is then the relative strength of the system against pirate designs. The question remains to be answered as to how much value does an ultimate scrambling system, designed within the realm of minor deviation from NTSC standard, have. Today, short of complete video encryption, the dynamic scrambling with encrypted key signal is most secure alternative one can offer.

ELIE - AN INTEGRATED BROADBAND COMMUNICATION SYSTEM USING FIBER OPTICS

G.A. TOUGH - Manitoba Telephone System
J.J. COYNE - Manitoba Telephone System

ABSTRACT

An integrated fiber optics distribution system has been installed in the rural communities of Elie and St. Eustache, Manitoba. The system provides single-party telephone, cable TV, FM stereo and Telidon videotex services to 150 households in the community. The paper gives a technical description of the trial system and summarizes the results obtained to date.

INTRODUCTION

Fiber optics offers broad bandwidth, low attenuation and many other unique and advantageous features. These features, in conjunction with its low-cost potential, make it attractive for application in virtually all areas of telecommunications; from long-haul transmission, to inter-office trunking, to local distribution. While the application of fiber optics in the local distribution network is generally agreed to represent a greater economic challenge, it also offers the greatest potential benefit and impact.

Recognizing this potential benefit and impact, and with a view to determine the technical and operational feasibility of fiber optics for local distribution and for rural service improvement, the Canadian Department of Communications and the Canadian Telecommunications Carriers Association, in co-operation with the Manitoba Telephone System have sponsored the field trial of a broadband integrated fiber optic distribution system in the rural community of Elie, Manitoba. The system, designed, developed and installed by Bell-Northern Research and Northern Telecom, was cut into operation in October 1981.

This paper starts with a discussion of the rationale for the trial. A description of the design and architecture of the trial system then follows. The installation, operation and maintenance aspects of the system are then discussed.

THE RURAL COMMUNICATIONS CHALLENGE

Rural communities were selected as the location for the trial because it is in rural areas where the improvement of communication services is a major concern, both to the Government and to the common carriers, and because fiber optics appeared to offer a potential solution.

Approximately 6 million people or 27% of the Canadian population live in an area exceeding 1 million square kilometers which is classified as rural by the Canadian Department of Communications. This definition of rural areas comprises small settlements and villages having a population of 2500 or less, as well as sparsely populated areas with a population density of at least one person per square mile. This rural area represents essentially the agricultural areas of Canada.

There are almost 700,000 rural subscribers on multi-party telephone lines and the number of customers on a single line can range up to 10, with an average of about 4.

The principle of equal access to communications services for all is a recognized premise of carriers and governments. It can be argued that a rural household has a greater need for improved communications because of the greater distances and isolation from the necessities and amenities of life. Substitution of improved communications for travel to conserve time and energy is becoming increasingly important. The social, economic and environmental problems associated with urban migration are also important considerations favouring the improvement of rural communications.

The major obstacle to improving rural service is, of course, cost, which increases rapidly as subscriber density decreases. An example is the MTS's Rural Service Improvement Program, completed in 1981. This program involved service improvement to 60,000 multiparty customers whereby 44,000 may have a maximum of 4 customers per line (average 2.8), and 16,000 customers receive individual line service based on a density criteria of at least 9 customers per kilometer. This program was implemented over a 6 year period at an average cost of $1,000 per customer, using paired copper combined with the latest analogue and digital subscriber carrier technology.

One potential solution to the cost problems is integrated distribution plant. Integrated plant, the electronic highway, with broadband capability offering overall cost savings and increased revenue potentials from cable TV and other new services, has been recognized for many years. The advent of fiber optics, coupled with other cost reduction developments such as large scale integrated circuits and microprocessors, indicate that the mid-1980's could see introduction of integrated fiber optics distribution plant.

Of course, the changeover to integrated plant will not occur overnight. The large existing capital investment in copper pairs, and the large amount of new capital required to install new integrated plant will force a progressive program over a number of years.

DESIGN CONSIDERATIONS AND SERVICES PROVIDED

The Elie, Manitoba, fiber optics experiment is actually two experiments rolled into one. It is a test of fibre optics in a rural setting, and it is a test of new communication services, again in the rural setting. This trial was initially proposed for a number of reasons:

1. No cost effective system exists today to provide a full range of telecommunications services to the low rural subscriber density in the agricultural plain of Manitoba. The density averages about 3 subscribers per square mile. This is representative of the Canadian prairie provinces.
2. It is considered desirable to test integrated distribution systems, capable of carrying not only telephone services, but also television, FM Stereo and Telidon videotex signals along with other as yet unidentified services. In effect, the electronic highway would be provided by MTS to be used by MTS and others.
3. The paired plant now providing the bulk of the rural facilities is limited to voice frequency use. While some rural carrier is placed on cable pairs, the circuits derived are for telephone or data services, but not for television.
4. The trial would encourage development of the technology of fiber optics, and gain experience in its application to rural areas.

The trial takes place in the exchange area of Elie and involves 150 subscribers. The subscribers include some residents in the town of Elie and the village of St. Eustache about eight kilometers north, and some farmers in the surrounding area. The system provides single party telephone, CATV and FM radio and a 56 kb/s data channel suitable for some inter-active computer services.

The 56 kb/s full duplex data channel is used to deliver Telidon videotex services, operating at the rate of 4.8 kb/s. Additional capacity is available in this data channel to provide other services if they should be required.

DESCRIPTION OF THE SYSTEM

The services are provided over a combination of laser and Light Emitting Diode (LED) driven loop circuits. Significant alternatives that are being examined include single fiber bidirectional transmission and simultaneous use of two independent video channels by individual subscribers.

A block diagram of the Elie-St. Eustache system is shown in Figure 1.

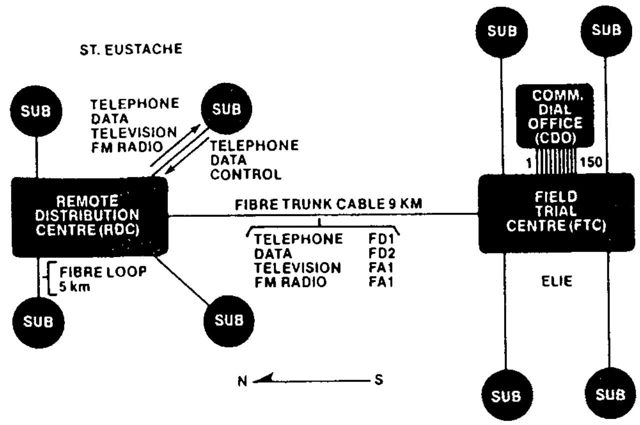


Figure 1 Elie and St. Eustache Switched Star Network Configuration.

The new fiber optics system is placed alongside existing copper facilities fed from the Elie Community Dial Office (CDO). The system architecture is based on a remote switched star configuration with two distribution centres connected by a dedicated fiber optic trunk cable. Telephone services over the trunk use the Northern Telecom Canada Ltd. (NTC) digital FD-1 system with a DS-1 rate of 1.544 Mb/s per fiber and the data services are provided over the NTC digital FD-2 system with a DS-2 rate of 6.312 Mb/s per fiber. The initial nine video channels are transmitted over the trunk fibers using the NTC analog FA-1 system. The FA-1 system is also used for the transmission of the seven FM channels over the trunk. Fiber distribution and fiber drop cables connect the distribution centres with the subscriber premises. Figure 2 shows the transmission frequency plan for integrated services over the fiber loop circuits.

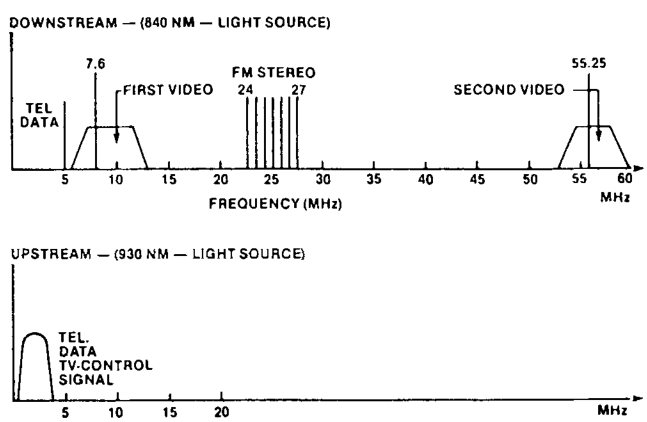


Figure 2 Loop Transmission Plan

For the basic service, the downstream light source at 840 nm is intensity modulated by a Frequency Division Multiplexed (FDM) signal containing one video signal, seven FM stereo signals and a Frequency-Shift-Keying (FSK) modulated carrier transmitting telephony, data and signalling in a Time Division Multiplexed (TDM) format. Video is transmitted in the standard NTSC-VSB-AM format on a visual carrier of 7.6MHz. Access of up to 12 video channels is provided by a video switch in the FTC and RDC. In the case of dual TV transmission, a second channel is added on a visual carrier frequency of 55.25 MHz. Pulse Code Modulated (PCM) voice and signalling are time division multiplexed with a 56 kb/s data signal, which is then bi-phase coded and FSK modulated on a 5 MHz carrier.

In the upstream direction, a light source at 930 nm is intensity modulated by a time division multiplexed data stream which consists of PCM-voice, signalling, 56 kb/s data and TV control signals for video switching and alarms. The composite signal is then bi-phase coded for base-band digital transmission to the distribution centres.

The fiber optic cable designed by NTC for transmission of signals between the distribution centres and over the loop circuits is filled with a dry powder compound and contains three to 36 fibers. Fiber parameters and cable installation details are shown in Figure 3. A cross-section of the NTC fiber optic cable is shown in Figure 4.

• FIBER PARAMETERS

TYPE	GRADED INDEX
PROCESS	I.V.P.
NA	0.17
ATTENUATION	<4 db/km (840 and 930 mm)
3 dB — OPT. BDW.	600 MHz
CORE — DIAM.	50 μm
CLADDING — DIAM.	120 μm
COATING — DIAM.	320 μm

• CABLE INSTALLATION DETAILS

TRUNK LENGTH	9 km
TOTAL LOOP LENGTH	75 km
CABLE PLACEMENT	70% BURIED 30% AERIAL

Figure 3 Fiber Parameters and Cable Installation Details.

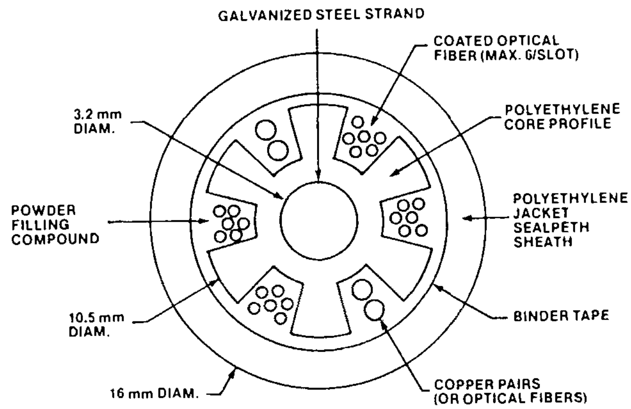


Figure 4 Cross-Section of NTC Optic Fiber Cable

The telephony service meets normal telephone loop requirements. The video and FM radio services meet normal distribution pérformance objectives. The 56 kb/s data performance is expected to be virtually error free.

FUNCTIONAL DESCRIPTION

The equipment located at the subscriber premises terminates the fiber loop and processes the received integrated signals for distribution to the various terminals. The units located at the subscriber premises are the Subscriber Entrance Unit (SEU), the Set Top Unit (STU) and the Remote Hand Held Controller (Rem.Ctl.) as shown in Figure 5.

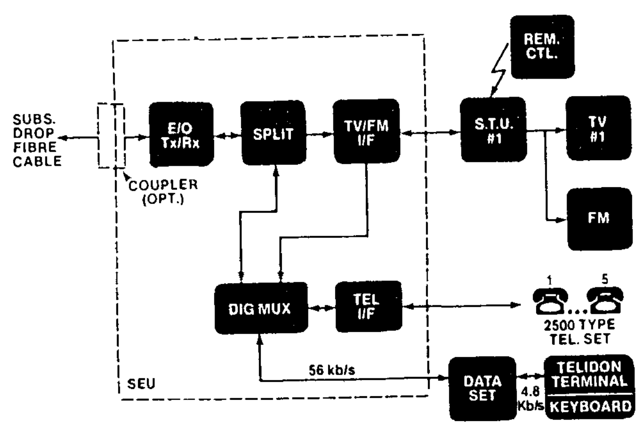


Figure 5 Subscriber Premises

Signals received by the SEU from the Line Interface Unit (LIU) and transmitted upstream to the LIU are shown in Figure 2. The STU is placed with the subscriber's television receiver. It receives infrared control signals from the Rem. Ctl. and displays the selected channel number. Connectorized access to the video and FM signals is also provided by the STU. The infrared control signals received by the STU are converted to a serial 200 b/s asynchronous start/stop format for transmission to the video switch in the LIU of the distribution centre.

Field Trial Centre (FTC)

Figure 6 shows the basic FTC system configuration. The DMS-1 Control Concentrator Terminal takes VF telephony inputs from the existing telephone switch and after digital encoding and multiplexing transmits them to two Remote Concentration Terminals (RCT), one in the FTC and one in the Remote Distribution Centre (RDC). These remote units are connected to the optical subscriber loops on a digital basis and provide the means for telephony concentration over the trunk facilities.

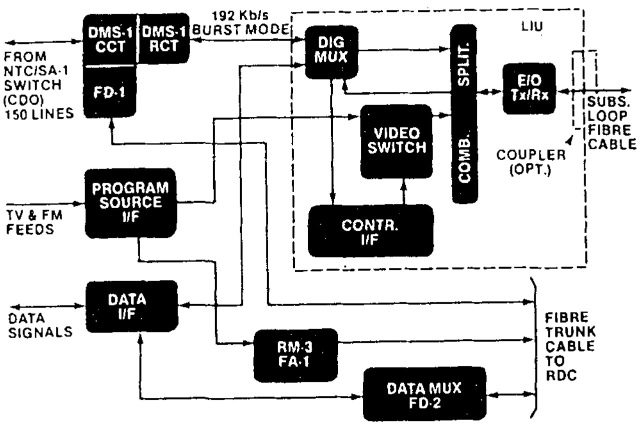


Figure 6 Field Trial Centre

In the program source interface, incoming television channels are demodulated and then transmitted to the RDC using an FM optical transmission system (RM3/FA-1). The channels to be distributed locally are remodulated into frequencies suitable for selection by the remotely controlled FDM video switch.

FM stereo program channels are similarly processed except in this case no switching takes place and all seven channels are transmitted to each subscriber.

The 56 kb/s data channel for each loop served directly by the FTC is time division multiplexed with the digitized voice and signalling. The composite bit stream is used to FSK modulate a 5 MHz carrier which is combined with the video and FM signals in the LIU. The optical transmitter in the LIU (either LED or laser) is intensity modulated by this composite signal for transmission to the subscribers. A composite signal that contains voice, data, signalling, TV control signals and system alarm information, is received from the subscriber's premises.

Remote Distribution Centre (RDC)

The RDC performs the same basic functions as the FTC, except incoming signals for distribution are derived from the FTC to RDC trunk system.

TECHNICAL SPECIFICATIONS

Telephone Service

Meets or exceeds present grade of service of the standards of the existing telephone network. This fiber optic system is designed to meet the following objectives:

- Idle Channel Noise	20 dBrnco	max
- Echo Return Loss	18 dB min	(C Message Weighting)
- Singing Point Return Loss	15 dB min	(C Message Weighting)
- Frequency Response Loss Relative to 1 kHz Loss	60 Hz	-20 dB min
Measured with 0 dBm0 Input	300-3200 Hz	+1.0 to -3.0 dB
	600-2400 Hz	±1 dB

Television and FM Stereo Service

Television meets or exceeds the Broadcast Procedure BP-23 Grade 1 performance objective at the subscriber set.

Data Channels

- Maximum bit error rate 10^{-6} for 99.9 per cent of the time at 56 kb/s, exclusive of outage.
- Zero blocking

PHYSICAL ENVIRONMENT

The physical environment on the Canadian prairie is a challenge to cable and equipment designers and manufacturers. While all electronics for the Elie trial are located in buildings, the cable and hardware is designed to meet the following environmental conditions:

- storage and transportation	-50°C to +55°C
- installation	-20°C to +50°C
- operation	-40°C to +55°C

The geographic environment of this part of Manitoba, commonly referred to as the Red River Valley, consists mainly of deep, boulder free clay-silt soil. The area is extremely flat; the change in elevation across the entire exchange area is less than 2.4 metres. The road borders are predominantly flat, free of fences and tree shrubs, and thus offer excellent terrain for cable ploughing. The existing cable is either buried or aerial, and the new fiber cable is also buried or aerial to test both methods of installation. In fact, the buried cables were placed above typical frost line.

EXPERIENCE WITH TRIAL SYSTEM

The trial system became operational in October, 1981, and will operate until the end of March, 1983. Experience with the trial system is limited at the time of writing.

Installation

A major contract was awarded to Northern Telecom Canada in 1979 for the design, development, manufacture and installation of the system. Much of the work was carried out by an associated company Bell-Northern Research. To facilitate the installation and associated equipment testing, trailers were used as the Field Trial Centre and the Remote Distribution Centre. The equipment was installed in the trailers at BNR in Ottawa, then transported by road to Elie.

The equipment installed in each subscribers home was installed by MTS personnel, and the fiber optics cables were installed and spliced by MTS construction crews through a sub-contract with Northern Telecom Canada. Training and instructional practices were provided by NTC. No serious problems were encountered during the installation phase. One goal of the trial was that regular construction crews could install the cables and equipment using standard installation equipment and procedures. This goal was met. The major change was the splicing of the optical fibers which required special training and special equipment.

Operation

The telephone, television, FM and Telidon services are all working satisfactorily. Trouble reporting procedures for the subscribers have been established. Procedures between the services providers, Manitoba Telephone System, the cable television licensee, and the Telidon data base providers have also been established.

Surveys will be taken over the duration of the trial to determine the subscribers' likes and dislikes, reactions and preferences, and usage of the service provided. Of major interest to the trial sponsors will be the subscribers' reaction to Telidon data base upgrades, to include messaging, interactive computer programs, etc.

Maintenance

Maintenance of the trial system is being performed by MTS maintenance personnel. Special training courses and maintenance practices were provided by NTC for the new and unique equipment. The maintenance philosophy is the same as for most modern equipment - field replacement of defective units and factory repair of those units. A stock of spare units on site is essential to keep the "mean time to restore" at a minimum.

A sophisticated alarm system complete with diagnostic features has been provided with the trial system to allow rapid identification of failed units and provide general system status.

The general maintenance experience to date has been good. There has been the usual "start up" problems which are being solved. A complete maintenance record is being kept so that analysis (Mean time between failure, mean time to restore, component failure patterns, fiber troubles, etc.) can be done on an ongoing basis.

SUMMARY OF TRIAL RESULTS

It is still too early for a complete summary. It is the plan of the sponsors of the trial to develop a System Evaluation Report to address all facets of the trial system from design to final disposition at the end of the trial.

At this time, it can be said that the system design meets the stated performance specifications and the system is operating satisfactorily.

ACKNOWLEDGEMENTS

The authors appreciate the input to this paper by K.B. Harris, Canadian Telecommunications Carriers Association, K.Y. Chang, Canadian Department of Communications, C.I. Nisbet, Northern Telecom Canada Ltd., and J.F. Chalmers, Bell Northern Research Ltd.

EVALUATION OF FEED-FORWARD AMPLIFIERS, MICROWAVE TRANSMISSION AND OTHER LONG-DISTANCE METHODS OF SIGNAL CARRIAGE

Donald Z. Dworkin

NYT CABLE TV, 120 West Merchant St., Audubon, N.J. 08106

ABSTRACT

The advent of 350, 400 and 450 Mhz systems has posed the requirement for improved methods of supertrunk design. The parallel development of feed-forward amplifiers and high channel capacity microwave has opened new possibilities which this paper explores by comparing designs for typical systems by each of these methods. A large range of numbers of channels, bandwidths and numbers of hubs are compared for system performance and costs.

The costs for each type of system are calculated on a per channel basis, per subscriber and per channel, per home. An assessment is made of reliability and operating costs for feed-forward and microwave. A single example each of an FM video and a fiber optic system are included for cost comparison.

INTRODUCTION

Many factors acting in the same direction are driving up the number of channels, bandwidths, geographical size, electronic complexity and performance standards for both new and rebuilt systems. These factors stem from the maturing of CATV, its increasing penetration nationally, particularly in urban areas, the competition of rival technologies such as MDS and DBS, the increased sophistication and demands of city and town councils, and finally the expectation of new services and customers. Therefore, there is a critical need for high capacity, high performance, reliable and economical methods of long-haul transportation which will establish hubs throughout the system area or carry the channels to the system extremities. Once the hub or extremity has been furnished with super high quality signal, local area distribution using traditional CATV hardware suffices to feed high quality signals to the subscribers.

Fortunately, technology seems to be keeping pace with demand in the form of high channel capacity microwave AML and feed-forward amplifiers with their unique distortion-cancelling networks. Both of these methods use AM which is bandwidth efficient and therefore a single link is capable of carrying 35 to 60 channels. Two other methods use FM; namely FM video cable and fiber optics. FM video cable has been proven to carry relatively small numbers of channels (less than half of an equal bandwidth AM system) with superb performance. For this reason as well as the high cost of AM-to-FM (and reverse) processing at each end, this method is considered only for a specific link. The last method, fiber optics, is considered only to compare it to the two AM methods. Both because of cost and lack of experience with large systems at this time, fiber optics is not further evaluated.

TYPES OF SYSTEMS

For cable, four bandwidths and their corresponding number of channels are analyzed; for microwave, two sizes of channel groupings are considered:

Cable

A) 300 Mhz
   1. 35 channels on one cable
   2. 70 channels on two cables
B) 350 Mhz - 44 channels
C) 400 Mhz - 52 channels
D) 450 Mhz - 60 channels

Microwave

A) 40 channels - 38 video channels
B) 54 channels - 52 video channels

Each of these systems was calculated for performance and cost, using comparable numbers of channels. In addition, costs were computed for four groups of system sizes, shown below, each consisting of variation of path lengths to the hubs ranging from 2.5 to 17 miles (See Table I):

	No. of Hubs	Total Miles
A.	5	50
B.	10	95
C.	15	140
D.	20	189

ASSUMPTIONS

A. It was assumed that three channels of reverse transmission were required for both cable and microwave.
B. Supertrunk:
   It was assumed that for purposes of reliability and maintenance that status monitoring

would be used not only to determine normal parameters but to monitor the condition of the feed-forward gain blocks. Since two identical integrated circuits are used within each gain block, if either should fail, only distortion parameters rise to the level of a standard circuit. Therefore, feed-forward amplifiers have built-in electronic redundance. Status monitoring enables the operator to replace the module before complete failure occurs.

B. A maximum cascade of 30 feed-forward amplifiers would be used, in order to stay within comfortable limits of maintainability.

C. Distribution:
Standard amplifiers such as the Jerrold SJ series (see Table 2) would be used for distribution from the hub with not over 20 amplifiers in cascade, again, in the interest of practical maintainability.

D. Cross-modulation distortion:
Cross-modulation is not specifically mentioned in the discussion since in systems of upwards of 35 channels, triple beat is the limiting factor.

E. Coherent carriers:
Tests demonstrate that coherent and harmonically related carriers provide a 10 db margin in subjective viewing of composite triple beat distortion **(1)**. This is reflected in the Minimum System Specifications, Table 3. However Table 10 gives the end-of-system specifications and maximum length for non-coherent systems of 300 and 350 Mhz; for a 400 Mhz system which could not reach as far as the longest hub required, the specifications and maximum reach are also listed. However, coherent carriers were assumed for this paper.

EQUIPMENT

A. Amplifiers - See Table 2.
1) Feed-forward amplifiers - The Century Model 4102-30-* was used.
2) Standard amplifier - The Jerrold Model 20/* was used for distribution from the hubs in both feed-forward and AML cases.

B. Microwave: The Hughes AML was used in its high-power version, Model AML-STX-141, for downstream application. The STX-151 was used for the upstream channels. The downstream broadband receivers with pilot tone AGC were used. The upstream receivers use composite AGC.

C. Cable: One inch (1") fused disc was used in the calculation for supertrunk simply because, as the lowest attentuation practical cable, the longest cascade and/or best specifications can be attained and therefore mark the practical limits for each design.

COSTS

I. Supertrunk

Actual figures were taken from construction bids and bills for a 300 Mhz feed-forward cascade in the NYT Cable system built by the author with a correction for the use of fused disc cable instead of .750 polyethylene cable actually used. The following Table 4 estimates cost for higher bandwidth systems based upon the increased attenuation. Costs include status monitoring and standby power.

Table 4
Costs Per Foot

System Bandwidth	300		350	400	450
Number of Cables	Single	Dual	Single	Single	Single
Electronics	.61	1.22	.66	.70	.75
Cable	.73	1.46	.73	.73	.73
Construct.					
Material	.21	.27	.21	.21	.21
Labor	.60	.65	.60	.60	.60
Engineering	.23	.30	.23	.23	.23
Total $/Foot	2.38	3.90	2.43	2.47	2.52
Total $/Mile	12566	20592	12830	13041	13305

System Performance Criteria (Table 5)

The amplifier levels were chosen so that the signal quality delivered to the hub permitted a reasonable standard trunk and feeder stem to emanate from the hub, serve all subscribers within the area and deliver pictures with substantially no observable degradation to the furthest subscriber. The specifications are shown for both supertrunk cable and microwave in Table 5.

System Costs

Costs/Channel/Home in Table 6 and Table 7 were calculated by assuming that each hub served an area of 5,000 homes, and that the penetration would be 50%.

II. Microwave

A.	Assume Existing Tower	$ -0-
B.	Differential tower hardware plus installation per hub	$ 2,000
C.	Antennae and waveguide/hub	$10,300

(1) Reference: Jerrold Technical Seminar, 3/26/80

D.	Incremental tower cost/hub	$ 3,000
E.	Transmit cost/hub minus Transmitter	$15,300

54 Channel Transmitter
52 video channels, 1 pilot tone and 2 FM modules (40 FM channels)

A.	14 8' racks w/multiplexing $2,325/ea.	$ 32,550
B.	38 Standard High power modules $11,850/ea.	$450,300
C.	17 Hyperband High Power Modules $12,975/ea.	$220,575
D.	Transmit Monitor $4,775/ea.	$ 4,775
	Transmitter Total	$708,200

54 channel Receive Cost

A.	54 Channel Receiver	$ 12,980
B.	CATV Interface	$ 1,735
C.	Antennae and Waveguide	$ 7,500
D.	Tower, Land, Building (Average)	$ 50,000
		$ 72,215

40 Channel Transmitter Cost
38 Video channels, 1 pilot tone, 2 FM modules (40 FM Channels)

A.	11 8' racks - $2,325 ea.	$ 25,575
B.	41 high power modules/$11,850 ea.	$485,850
C.	Transmit monitor	$ 4,775
	Transmitter Total	$516,200

40 Channel Receiver Cost

A.	40 Channel Receiver	$ 10,820
B.	CATV Interface	$ 1,445
C.	Antennae and Waveguide	$ 7,500
D.	Tower, Land, Building (Average)	$ 50,000
		$ 69,765

Upstream Transmitters

3/Hub-Select as required:		Per Channel
A.	STX 451 B: + 10 dbm sites between 1-8 miles	$ 6,380
B.	STX-151C:+17 dbm out (sites between 8-12 miles)	$ 7,580
C.	STX-151D:+ 20 dbm out (Sites greater than 12 miles)	$ 9,215
D.	Rack and Multiplexing/site	$ 2,325

Upstream Receivers

A.	Receiver One required per two hubs	$ 10,820

RELIABILITY

A typical 9 mile path is taken as the basis for comparing the reliability of supertrunk cable and AML.

A. Supertrunk

A 9-mile supertrunk in a 400- Mhz system uses 1.28 feed-forward amplifiers per mile (see table 5). Thus, 12 amplifiers would be used. Modern amplifiers have MTBF's of better than 200,000 hours. Even assuming half of this figure, a cascade of 12 amplifiers would have an overall MTBF of $\frac{100,000}{12} = 8,333$ hours or 1 failure per year per supertrunk. If status monitoring is used with feed-forward amplifiers which contain "redundant" chips (see Assumptions, B) this figure could be greatly improved.

B. AML

The figures used are based upon curves, data and estimates supplied by the manufacturer except for the path reliability figure which was calculated using average terrain and rain figures for the southern New Jersey area with an average transmitter wave guide of 200 feet, a receiver wave guide of 100 feet and circular dual polarized antennas and wave guide, and a duration of 15 minutes per failure.

Table 8

Element	MTBF
Transmitter, High power array	8,800
Path, rain and multi-path	1,666
Receiver, broadband	10,000

Total combined or system MTBF is 1,229 which is equivalent to approximately 7 failure per year. Two factors which should be taken into account are, firstly, that a failure of one transmitter module only causes a single channel failure, all other element failures causing total failure. The second point is that local conditions have a drastic effect on path reliability. Therefore, path calculations serve only as a basic, average guide with variations due to local conditions.

MAINTENANCE COSTS

AML

Taking a 54 channel AML transmitter as reference, the average annual replacement cost for klystrons and miscellaneous parts of $250 per channel would be, assuming klystrons last for 3½ years, costing $2,200 each:

$$54\left(\frac{2,200}{3.5} + 250\right) = \$52,920/\text{year}$$

Adding 1 technician for maintenance, at $18,000 salary, his system cost would be $36,000. The total annual maintenance cost would be $88,920.

Supertrunk

Based upon the MTBF previously calculated and a material cost of $75 per failure, the following costs would be incurred:

Table 9

No. of Hubs	5	10	15	20
No. of Amps	70	140	210	280
No. of Failures	7	14	21	28
$/Parts Cost	500	1,000	1,500	2,000
1 PM Tech.	24,000	24,000	24,000	24,000
¼ DM Tech.	4,500	4,500	4,500	4,500
Total Cost/ Per Year	29,000	29,500	30,000	30,500

Over a one-year period, the cost savings would be approximately $60,000 for supertrunk compared to an AML installation.

Additional Transmission Methods

A. Fiber Optics

The cost of a fiber optic system designed for an 11-hub system, carrying 35 channels is detailed below.

One-Way Electronics, Fiber Optic Cable:	$2,555,000
Fiber-Optic Electronics, Cable for Reverse:	$ 200,000
Demodulators for off-air:	$ 46,000
Remodulators - 35 x 2,000 x 11:	$ 770,000
Buildings at receive sites - 11 x 54,000:	$ 594,000
Installation	$ 350,000
Total	$4,515,000

The costs for an equivalent 35-channel, 11-hub system by AML and feed-forward methods are:

Feed-Forward Supertrunk:	$1,300,000
AML Microwave:	$1,800,000

B. FM Video

A point-to-point, dual cable transmission capable of transporting a total of 44 channels plus FM broadcast signals is estimated for a path length of 10 miles.

Head-end Electronics - 44 x $4,300:	$ 189,200
Receive Electronics - 44 x $4,300:	$ 189,200
Receive Building:	$ 54,000
Cable and Amplifiers, 10 miles x $12,830/mile	$ 128,300
Total	$ 560,700

Equivalent feed-forward and microwave systems' costs for a single 10 mile link are:

44 Channels, feed-forward	$ 120,830
38 Channels, AML	$ 695,000
54 Channels, AML	$ 890,000

CONCLUSIONS

1. Supertrunks can be constructed in 450 MHz systems up to 22 miles in length, using feed-forward amplifiers.

2. a. In all types of systems, feed-forward supertrunk costs approximately $500,000 less than microwave, with the difference remaining approximately the same with increasing number of hubs.

3. Costs per channel per home: These become less for both cable and microwave as:
   a. The bandwidth and number of channels become higher.
   b. The number of hubs increase.

4. Costs per subscriber:
   a. For microwave - decrease by approximately 20% for each doubling of subscribers.
   b. For cable - remain about the same as the number of subscribers increase.

5. Cost per channel:
   a. For microwave -decreases by 25% from 38 channel to 52 channel equipment.
   b. For cable - decreases by 30% from 300 MHz to 450 MHZ.

6. Microwave versus feed-forward supertrunk cable:
   a. Reliability - Mathematical prediction shows a theoretical superiority of cable over microwave, although actual experience and field conditions may considerably modify this.
   b. Maintenance Cost - indicates an annual savings of approximately $60,000 for cable over microwave.

My grateful appreciation goes to Mr. Bruce Adams and Mr. Bill Hindman for their careful work in compiling up-to-date cost figures for feed-forward supertrunk and AML respectively. I, of course, remain responsible for checking and using their data.

TABLE 1

MODEL SYSTEM CONFIGURATIONS

Hub	Ground Miles From Head End	Number of Hubs Selected for Model			
		5	10	15	20
1. Alpha	2		X		
2. Bravo	4.5			X	
3. Charlie	4	X			
4. Delta	6				X
5. Echo	6		X		
6. Fox	6				X
7. George	7.5			X	
8. Hotel	8				X
9. India	8	X			
10. Juliet	8.5			X	
11. Kilo	10		X		
12. Lima	10	X			
13. Mike	10.5			X	
14. Nan	12				X
15. Oboe	12		X		
16. Peter	12	X			
17. Queen	14			X	
18. Romeo	15		X		
19. Sugar	16	X			
20. Tango	17				X
	Total Miles Supertrunk	50	95	140	189

TABLE 2

Amplifier specifications

	Standard Amplifier				Feed-Forward Amplifier			
Bandwidth, Mhz	300	350	400	450	300	350	400	450
Channels	35	44	52	60	35	44	52	60
Gain, db.								
Maximum	26	26	26	26	34	34	34	34
Operating	25	25	25	25	30	30	30	30
Levels, dbmv								
Output	32	32	32	32	40	40	40	40
Input	7	7	7	7	10	10	10	10
Composite Triple Bed, db, at Operating Level	-92	-88	-84	-82	-102	-100	-98	-96
Noise Figure, db. (0 pad)	7	7	7	7	10	10	10.5	10.5
Power								
Watts	30.3	30.3	30.3	30.3				
Amps	0.55	0.55	0.55	0.55	1.0	1.0	1.0	1.0

TABLE 3

MINIMUM SYSTEM SPECIFICATIONS

	HUB		LAST TRUNK		SUBSCRIBER	
	Non-Coherent	Coherent	Non-Coherent	Coherent	Non-Coherent	Coherent
Carrier to Noise, db	47	47	45.2	45.2	45	45
Carrier to Composite Triple Beat, db	67	57	59	49	53	43
Carrier to Second Order, db	66	66	63	63	60	60

TABLE 5

SUPERTRUNK SYSTEM PERFORMANCE

Feed-Forward Amplifiers, Harmonically Related

Bandwidth		300	350	400	450	Microwave (AML)	
Number of Channels		35	44	52	60	38	52
Cable attenuation,db/M', max.		6.3	6.8	7.3	7.8		
Supertrunk(Feed-Forward Amps)							
Number of Amps/ @ 30 db spacing		19	21	22	24		
Number of Amps/ Mile		1.11	1.20	1.28	1.37		
Operating Levels	Sin/Sout	16/46	16/46	16/46	16/46		
	C/N	51	51	50	50	53	53
	C/CTB	64	62	59	57	75	70
Distribution(Standard Amplifier)							
Number of Amps		20	20	20	18		
Operating Levels	Sin/Sout	9/34	9/34	9/34	9/34	9/34	9/34
	C/N	47	47	47	47	47	47
	C/CTB	62	60	54	53	62	54
Total System							
Combined Specs.	C/N	45.5	45.5	45.2	45.2	46	46
for worst case at last trunk amp.	C/CTB	57	55	50	49	60	52.7
Maximum Supertrunk Cascade		45	40	36	31		
Maximum Distance	1.00" cable/miles to still meet: C/N=47 C/CTB=57	40.6	33.4	28.1	22.6	17	17
	.750 cable/ miles: C/N=47 C/CTB=57	28.4	23.3	19.6	15.8		

TABLE 6

SUPERTRUNK COSTS

M=Thousand Dollars
$=Dollars

Number Of Hubs	Total Miles (Actual Ground	Cost Units	Bandwidth, Mhz	300		350	400	450
			No. of Channels	35	70	44	52	60
No. of amp./mile for 1" fused disc cable				1.11	1.11	1.20	1.28	1.37
5	50	M	Total Cost	628.3	1029.6	641.5	652.1	665.3
5	50	M	Cost/Channel	17.8	14.7	14.6	12.5	11.1
5	50	$	Cost/Sub.	50.3	82.4	51.3	52.2	53.2
5	50	$	Cost/Ch/Home	.71	.59	.58	.50	.44
10	95	M	Total Cost	1193.8	1956.2	1218.9	1239	1264
10	95	M	Cost/Channel	34.1	28.0	27.7	23.9	21.1
10	95	$	Cost/Sub.	47.8	78.2	48.8	50	50.6
10	95	$	Cost/Ch/Home	.68	.56	.55	.48	.42
15	140	M	Total Cost	1759.3	2882.9	1796.3	1825.8	1862.8
15	140	M	Cost/Channel	40.3	41.2	40.8	35.1	31.0
15	140	$	Cost/Sub.	46.9	76.9	47.9	48.7	49.7
15	140	$	Cost/Ch/Home	.67	.55	.54	.47	.41
20	189	M	Total Cost	2375	3891.9	2424.9	2464.9	2514.8
20	189	M	Cost/Channel	67.9	55.6	55.1	47.4	41.9
20	189	$	Cost/Sub.	47.5	77.8	48.5	49.3	50.3
20	189	$	Cost/Ch/Home	.68	.56	.55	.47	.42

TABLE 7

MICROWAVE SYSTEM COSTS

All Figures in Thousands Except Cost/Channel/Home and Cost/Subscriber (Designated $)

A) 52 Channels & FM Radio & Pilot

Number of Hubs	5	10	15	20
Downstream				
a. Tower	76.5	153	229.5	290.7
b. Transmitter	708.2	708.2	708.2	708.2
c. Receiver:	361	722	1,083	1,371.8
Upstream				
a. Transmitter	131.3	259.2	382.1	509.9
b. Receiver	32.4	51.4	81.6	108.2
Total	1,309.4	1,893.8	2,484.4	2,988.8
Rounded off cost	1,300	1,900	2,500	3,000
Cost/Channel	25	36.5	48.1	57.6
Cost/Subscriber	$104.72	$75.75	$66.20	$59.78
Cost/Channel/Home	$1.00	.73	.64	.58

B) 38 Channels & FM & Pilot

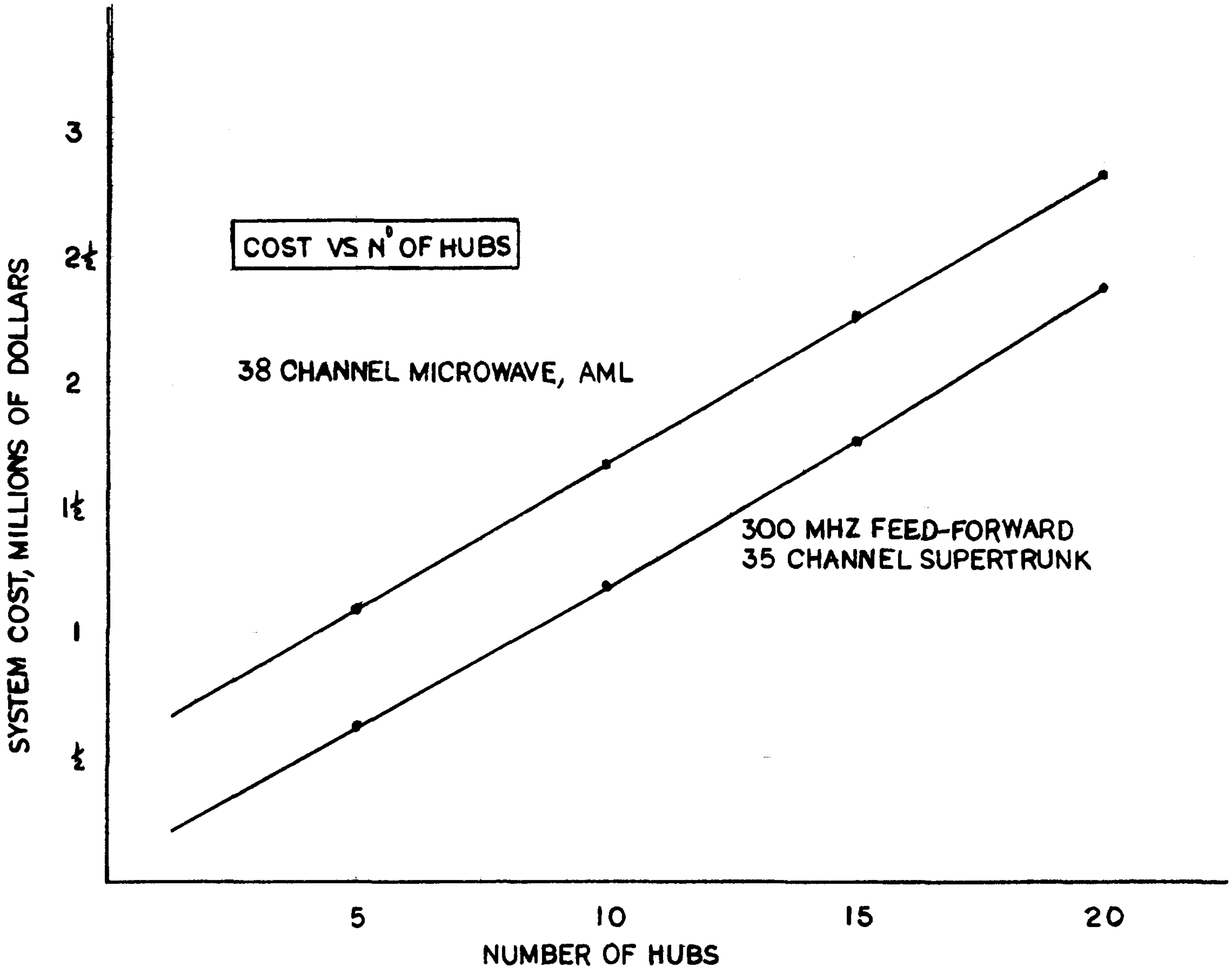
Downstream				
a. Tower	76.5	153	229.5	290.7
b. Transmitter	516.2	516.2	516.2	516.2
c. Receiver	348.8	697.7	1,046.5	1,395.4
Upstream				
a. Transmitter	131.3	259.2	382.1	509.9
b. Receiver	32.4	51.4	81.6	108.2
Total	1,105.2	1,677.5	2,255.9	2,820.4
Rounded Off	1,100	1,700	2,300	2,800
Cost/Channel	29.1	44.1	59.4	74.2
Cost/Subscriber	$88.40	$67.08	$60.16	$56.40
Cost/Channel/Home	$1.16	.88	.79	.74

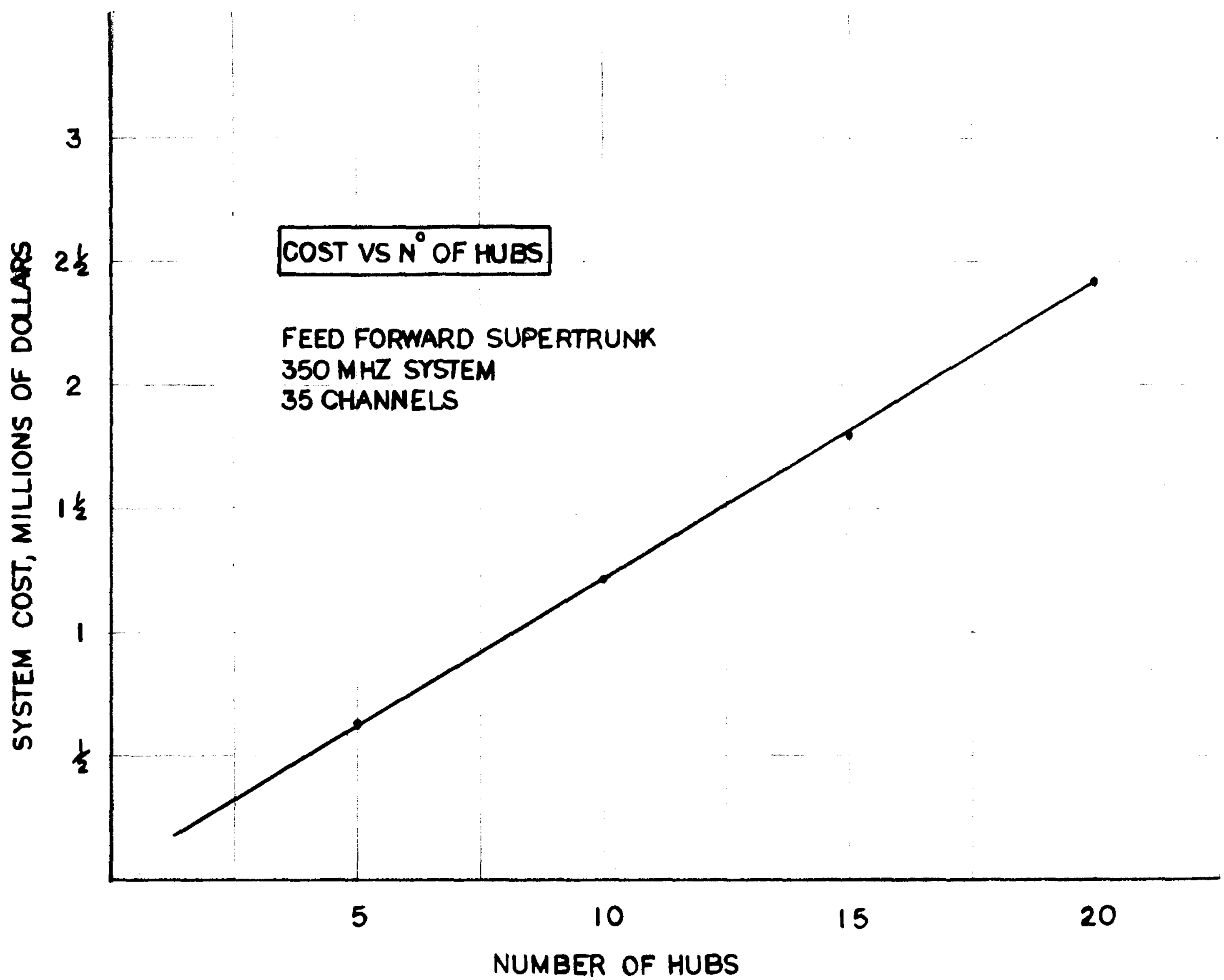
TABLE 10

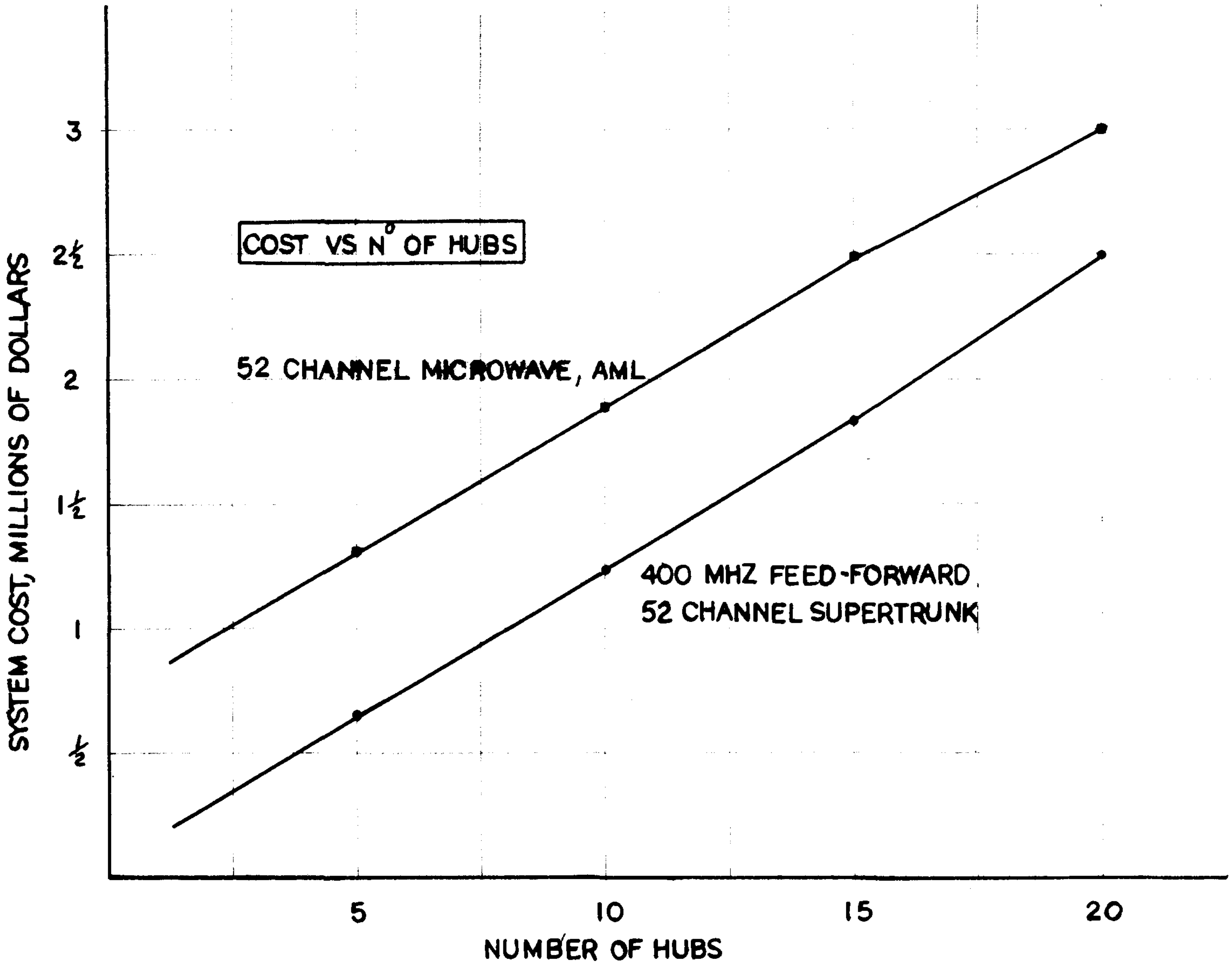
Supertrunk System Performance; Non-Harmonically Related Carriers

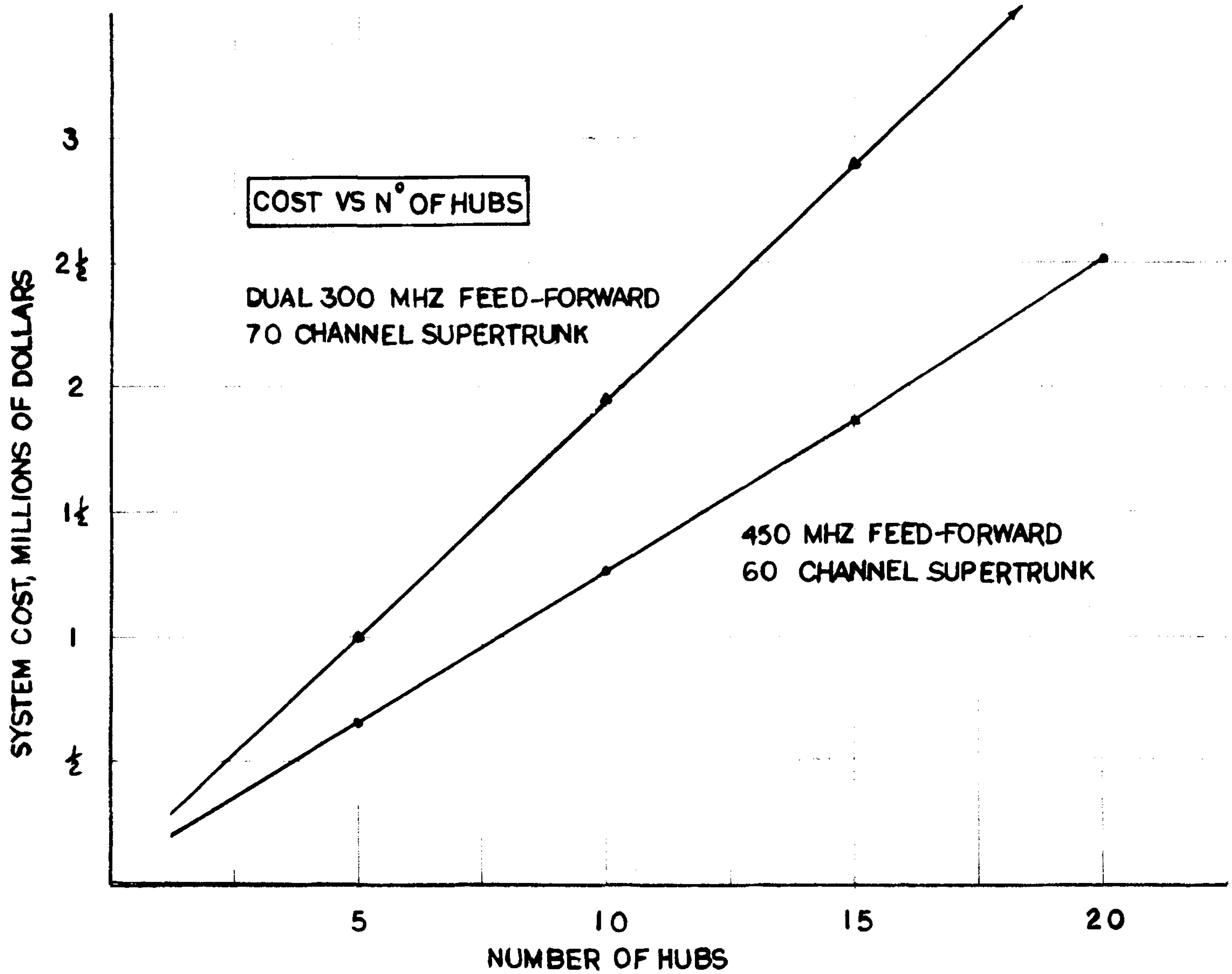
Bandwidth		300	350	400
Number of Channels		38	44	52
System Length, Miles		17	17	
Number of Amplifiers Required		19	21	
Feed Forward Amplifiers	Input/Output	14/44	14/44	
	C/N	49.2	46.7	
	C/CTB	68	67	
Standard Amplifers	#	20	20	
	C/N	47	47	
	C/CTB	62	60	
Combines specifications (Total System)	C/N	45	44.7	
	C/CTB	59	56.7	

Maximum Miles	1" Disc	24.2	20.	15.6
	0.750	17	14	10.9
Maximum No. of Amps		27	24	20
	C/N	47	47	47
	C/CTB	67	67	67


COST VS N° OF HUBS
38 CHANNEL MICROWAVE, AML
300 MHZ FEED-FORWARD
35 CHANNEL SUPERTRUNK
SYSTEM COST, MILLIONS OF DOLLARS
3
2½
2
1½
1
½
5
10
15
20
NUMBER OF HUBS


COST VS N° OF HUBS
FEED FORWARD SUPERTRUNK
350 MHZ SYSTEM
35 CHANNELS
SYSTEM COST, MILLIONS OF DOLLARS
3
2½
2
1½
1
½
5
10
15
20
NUMBER OF HUBS


COST VS N° OF HUBS
52 CHANNEL MICROWAVE, AML
400 MHZ FEED-FORWARD
52 CHANNEL SUPERTRUNK
SYSTEM COST, MILLIONS OF DOLLARS
3
2½
2
1½
1
½
5
10
15
20
NUMBER OF HUBS


COST VS N° OF HUBS
DUAL 300 MHZ FEED-FORWARD
70 CHANNEL SUPERTRUNK
450 MHZ FEED-FORWARD
60 CHANNEL SUPERTRUNK
SYSTEM COST, MILLIONS OF DOLLARS
½
1
1½
2
2½
3
5
10
15
20
NUMBER OF HUBS

FAILSAFE TECHNIQUES

DONALD E. GROFF

GENERAL INSTRUMENT JERROLD DISTRIBUTION DIVISION

Techniques for maintaining distribution system continuity in the event of mechanical or electrical failure are discussed. The probability of various types of failure are considered, and various means of dealing with different types of failures are evaluated. Such means include backup devices, redundant devices, and amplifier bypass networks of several types. Amplifier bypass techniques are considered in more detail, including choice of switching devices, means of controlling the bypass function, and system performance under bypass conditions.

INTRODUCTION

This paper is concerned with provisions for keeping a CATV distribution system in operation in the event of electrical or mechanical failure. We will concern ourselves with outside plant only, between the headend and the subscriber drop, and primarily with trunk amplifiers.

With traditional entertainment services, any downtime is certainly not to be taken lightly, but with expanded premium services, and especially with the growth of data communication service, keeping the system in operation in all circumstances has become crucial.

TYPES OF FAILURE

To consider how to deal with failures, we need to list the possible range of events to be contended with. For some interruptions there is little that can be done other than repair the damage. Examples are a cable severed by fire, storm, or accident, or a direct hit by lightning.

Here are some events which result in an interruption of service, for which failsafe provisions might be made. They are arranged in a rough order of decreasing probability:

1. Loss of AC power at an amplifier station.
2. Loss of DC power at an amplifier station.
3. Electronic failure in an amplifier active device.
4. Mechanical failure in an amplifier active device.

Another event might be added to this list. It is:

5. Interruption for service reasons, e.g. removal of module for test or replacement.

This last item is not normally considered a failure, but a means of avoiding outage for this reason would be useful.

Event #1, of course, causes Events #2 and #3. In recent years, standby power supplies have come into wide usage despite their cost and complexity. Any device intended to improve system reliability must itself be extremely reliable, and a standby supply, with its sophisticated electronics, is a potential point of failure, but many consider standby supplies to be essential.

POWER FAILURE

Perhaps the most common failure in current distribution equipment is loss of station DC power. Transformers and rectifier circuits generally are very rugged in today's amplifiers. The electrical and economic requirements on regulator circuits, e.g. efficiency, put some limit on the degree of ruggedness which can be achieved.

A backup DC regulator is sometimes used, in a configuration which switches it into operation in case of failure of the primary regulator. It is desirable to have this condition reported by a status monitoring system, so that the failed regulator may be replaced.

RF FAILURES

Failure within the RF circuitry is more difficult to deal with. There are many possible points of failure. Fortunately, the active devices themselves have become much more reliable since the early days of the CATV industry, and many consider modern hybrid integrated circuits to be essentially the most reliable element in the system. The associated passive components are highly reliable, but the large number of interconnections made necessary by the requirements of modularity are associated with occasional mechanical failure. It is very difficult to guard absolutely against an occasional cold solder joint or a loose piece of wire.

A less severe kind of interruption is the one caused by deliberate removal of a module for service reasons. Of course, the module might have been removed because it had failed completely. But if the amplifier was operating in a degraded manner, the immediate, if temporary, result of removing it is a castatrophic failure. System continuity in this case would be a benefit.

How should these possible events be dealt with? In general, it is desirable to provide an alternative for any system element which is prone to failure. In the extreme, this leads us to dual cable systems, separately powered, but we want to stop short of this. We will restrict our attention to the amplifier stations, primarily trunk amplifiers.

REDUNDANT AMPLIFIERS

Redundant amplifiers, run in parallel with 3 dB splitters at the input and output, are sometimes used, as shown in Figure 1. Failure of one amplifier causes a 6 dB drop in signal level, but no protection against power failure is achieved. There are several other important factors to be considered with hot redundancy: power consumption and heat dissipation are increased; distortion is reduced, since each amplifier runs 3 dB lower in level; and noise figure is slightly worse, by about 0.5 dB, due to non-ideal splitters.

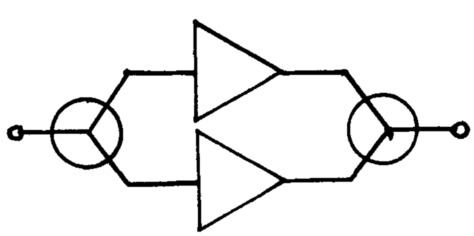


Figure 1. Redundant Amplifier

BYPASS TECHNIQUES

The technique to be discussed at some length here is in effect to remove a failed trunk amplifier from the system and replace it with a jumper cable. This must, of course, be done electrically and in some way automatically. See Figure 2. The bypass might be done separately for the forward and reverse amplifiers, but this would remove the trunk filters from the bypass network. The bridger amplifier and reverse feeder circuitry might also be bypassed, although there are pros and cons here.

The approach to be described here is to bypass as much of the RF path within the trunk station as possible. This is done with double throw switches at the input and output of the station. The AC power through the station is not switched, as this path has a relatively low probability of failure, and switches designed for 60 Hz power do not readily lend themselves to UHF RF transmission.

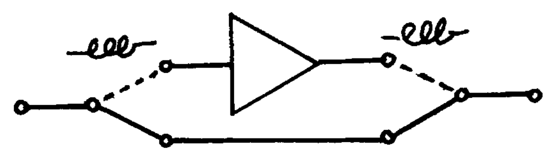


Figure 2. Amplifier Bypass

CHOICE OF SWITCHES

It goes without saying that the switches themselves must be highly reliable, if this circuitry is to enhance the overall system reliability. There is another hazard; the bypass circuitry constitutes a potential feedback path around broadband RF amplifiers. This requires that the switch isolation in the normal mode of operation be very good, since even small amounts of uncontrolled feedback can cause amplitude distortion in the transmission.

What sort of switches are to be used? Diode switches would seem to be the preferred way to switch broadband RF paths. However, this system must work in the absence of AC or DC power. This would require a battery or perhaps a large capacitor as a backup bias source. This is a major, but not insurmountable, problem, but there are other factors which weigh against diode switches.

The potential distortion which diode switches might add to the system is a potential problem, but one which is predictable and manageable. The requirements for a backup bias source favors low bias currents, which are generally imcompatible with low distortion. A more serious potential problem is the surge susceptibility of a semiconductor diode located directly at the input and output of the amplifier station.

A major factor in the improved electrical ruggedness of today's amplifiers is the fact that the active devices are well buffered from the input and output. Pushpull circuits with transformer coupling and two way filters contribute to this buffering. The station input and output, which is where the bypass switches should be located, are very hazardous locations for bandswitching diodes.

This brings us to electromechanical devices, which have the proper power-down state, are not likely to contribute distortion, and are relatively immune to surges. Of course, as system frequencies move into the UHF band, the relay must be carefully chosen. Preferred devices are those designed specifically for RF operation for frequencies in this range.

BYPASS CONFIGURATION

A pair of double throw relays, as shown in Figure 2, form a basic failsafe bypass configuration. In the simplest mode of operation, the relay coil is operated by the station's DC power, so that when the DC power is down for any reason, the station is bypassed. A more sophisticated means of control of the switches will be described later.

In Figure 3, several of the elements of a real trunk amplifier station are added, specifically two way filters and reverse amplifier, and the AC power network.

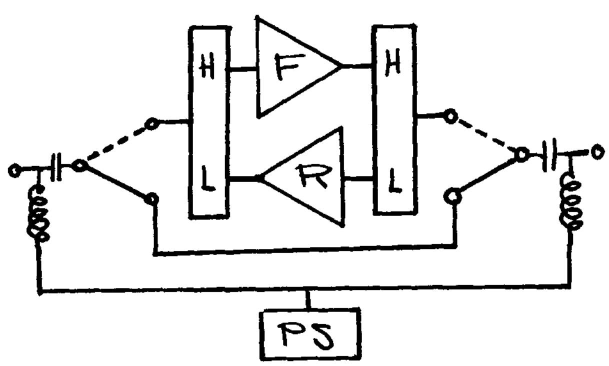


Figure 3. Trunk Station

In Figure 4, a bridger amplifier has been brought into the picture and for simplification, two way filters are not shown. In this situation, the bridger amplifier can also be bypassed, with an additional switch. Of course, the bridger amplifier could be separately bypassed with a pair of switches, but the complexity grows rapidly. In the simpler version, a splitter is incorporated into the bypass network, to maintain continuity to the feeders. Note that this increases the loss in the trunk path when the bypass is active.

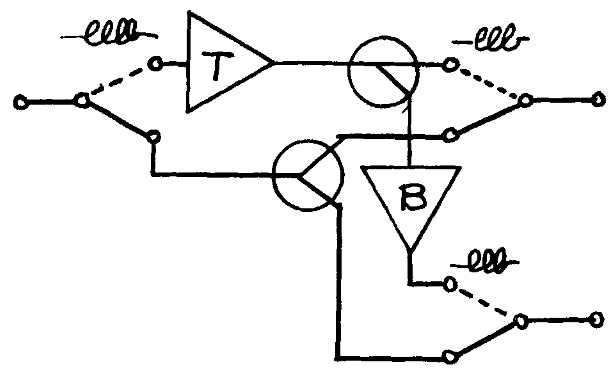


Figure 4. Trunk/Bridger Bypass

If a bridger amplifier is to be bypassed, then the line extenders in the corresponding feeder lines might be bypassed as well. A choice is at hand, whether to degrade the trunk performance in the interest of keeping continuity to the feeders. Signal level considerations, to be discussed later, suggest that the trunk ought to be maintained at the expense of an individual bridger service area.

STATUS MONITOR

If the switches are controlled by the station DC supply, then the bypass is automatic, in the power down case. To deal with other types of failure within the amplifier, a status monitor system is essential. The system must be capable of causing the bypass switches to be activated under remote control. It must be configured so that a failure which would require the failsafe system to activate does not disable the status monitor system which controls the switches! Figure 5 indicates the proper configuration. The signal pickoff for the status monitor receiver must be put upstream from the switches and station. This allows communication and control to be maintained in the event of failure of the forward amplifier.

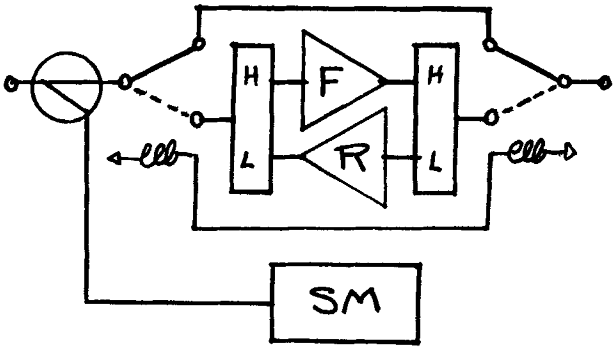


Figure 5. Status Monitor Connection

SYSTEM PERFORMANCE IN BYPASS

What happens to system performance if one trunk amplifier in a long cascade is bypassed? The gain of that station, of course, drops to a bit less that 0dB. If we consider a trunk spacing of 21 dB at 450 MHz, the bypass will drop signals by about 21 dB, but that is only at the 450 MHz. At 50 MHz, the spacing is only about 7 dB. The succeeding AGC/ASC amplifiers will pull the signal levels back up to normal levels, providing some reserve gain is available in the amplifiers, which is normally the case. The carrier to noise ratio will, of course, suffer because of the low input levels, but nowhere near the 7 to 21 dB which might be suggested by the localized loss in level.

Frequency, MHz	50	200	450
Cable Loss, dB	7	14	21
Normal Amplifier Gain, dB	7	14	21
Amplifier Noise Figure, dB	9	9	9
Normal Input, dBmV	10	10	10
Reserve Amplifier Gain, dB	4	3	2
Number of Amps to Recover Normal Signal Level	3	6	12
C/N at Point of Level Recovery, dB	51.1	43.1	34.7
Normal C/N at This Point, dB	55.2	52.2	49.2

Table 1. System Performance in Bypass

Table I indicates the results of carrier to noise calculations for a case in which the first amplifier in a cascade is bypassed. The table indicates 3 frequencies, with the normal spacing and reserve gain for each. The number of succeeding AGC/ASC amplifiers needed to restore normal levels is shown, along with the resulting carrier to noise at the point of restoration, as well as the normal C/N at that point. Note that in the low band the degradation from a station bypass is very much localized. In a failsafe system, the most essential services, e.g. data communications, should be located at the lower frequencies.

FEEDER LINES

Bypass circuitry could be provided for line extenders. But level recovery is not feasible, since line extenders are not normally cascaded more than 2 or 3, and AGC line extenders are relatively uncommon in any event. If as mentioned above we consider AC failure to be a major reason for failsafe circuitry, line extenders will go into bypass at the same time as the trunk station which feeds them AC, as well as, RF goes into bypass. This requires putting additional loss into the trunk bypass path, as shown in Figure 4. It would appear that it is preferrable to sacrifice the feeders for a given bridger service area in the interest of maintaining the trunk as clean as possible.

CONCLUSION

System continuity in event of failure may be maintained by a variety of techniques. It is important to determine the probability of the types of failure to be dealt with, and establish what action is to be taken for different types of failure.

FILM IN A TELEVISION ENVIRONMENT

DOM STASI

VICE PRESIDENT
NETWORK OPERATIONS & DESIGN ENGINEERING

WARNER AMEX SATELLITE ENTERTAINMENT COMPANY
NEW YORK, NEW YORK

ABSTRACT

Variety notwithstanding, the staple of pay T.V. programming remains the feature film.

It is interesting to consider then that most feature film material was never produced for television viewing. Primarily intended for theatrical exhibition, film characteristics such as light transfer function or aspect ratio are not readily compatible with display on the small screen.

Therefore, if we are to maintain fidelity of light and shadow, scene content, and sound that the director intended, the transfer characteristics of the electronic system (camera / tape / transmission / distribution / T.V. receiver) must be considered. Very significant progress has been made in this regard in the recent past through waveform pre-distortion, camera target matertials etc.

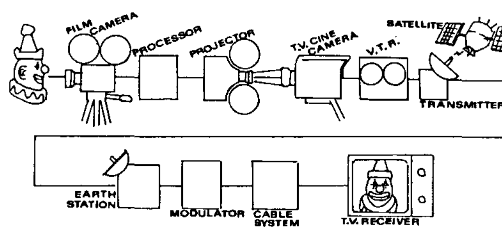
Engineering efforts in this regard by The Movie Channel, as well as other pay programmers, will be described and augmented by demonstrations of processed, as well as "straight", film to tape transfers.

INTRODUCTION

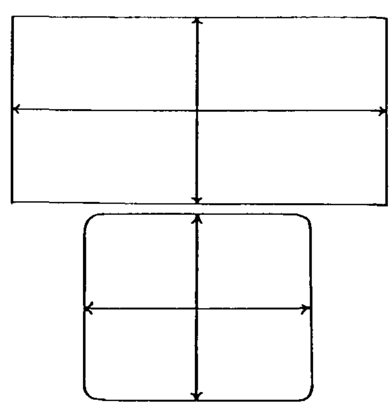
To appreciate the nature of film to television conversion, it becomes necessary to dismiss the pre-conception that the two mediums are strongly similar. Of course, both use cameras and screens and microphones and actors; but similarities end at the artistic level (there are those who would claim that no similarity whatsoever exists here either). In fact, dissimilarities render the two nearly incompatible; with film being by far the more potent genre in both its capability for artistic expression and quality of reproduction. While this statement may constitute heresy by a TV practitioner at a TV conference, anyone ready to dispute it need only compare quality theatrical reproduction with that of large screen projection television (or small screen direct television) to mention nothing of sound track. However, unless you happen to live next door to a drive-in theater, it is at best difficult to watch large screen feature film entertainment by direct projection from your living room.

Television is the only medium with such versatility and its overwhelming audience acceptance obviates all comparative discussion. Therefore, our audience has given us our mandate. If then any semblance of film quality is to be maintained, the inherent aspects of the television reproduction system must be altered to that effect.

Figure 1 illustrates the stages a filmed image undergoes on its way to the TV viewers eyes.



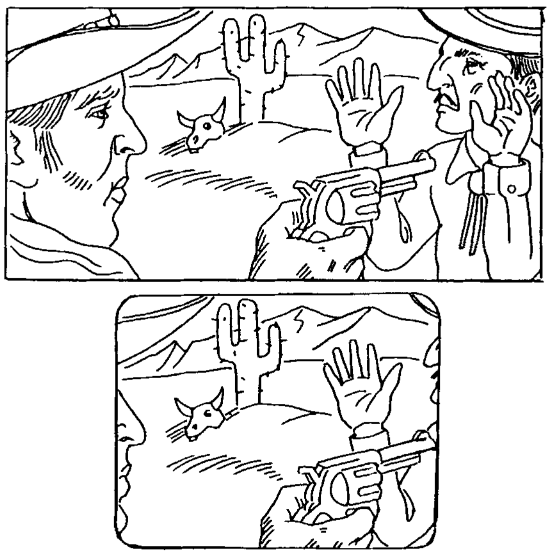
Each element exhibiting its own inherent non-linearities to the general detriment of reproduction quality. The most evident of these, is that of "aspect ratio", as shown in figure 2.



Aspect ratio, the relationship of height to width in a reproduced picture, varies drastically between a frame of film and that of TV.

Film producers, in an effort to more closely duplicate the field of vision, have developed wide aspect ratio formats such as cinemascope (8:3) while television, limited by bandwidth subordinate standards, is fixed at 4:33.

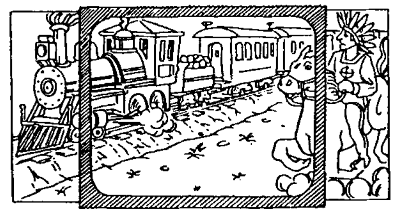
Film directors take full advantage of the wider field and frequently place subjects at the edges of a frame. As figure 3 illustrates when that frame is converted to TV without some alteration the result can be catastrophic.



The intent of this paper will be to illustrate this as well as the less apparent but no less detrimental incongruities extant in the translation of theatrical release motion pictures to television. The input (film) and the output (TV receiver) are generally outside of our control. While most other elements in the system such as VTR's and transmission equipment are essentially linear. That leaves those devices at the interface, the projector and TV camera and associated optics, as the most likely to exhibit alterable transfer characteristics.

<u>ASPECT RATIO</u>

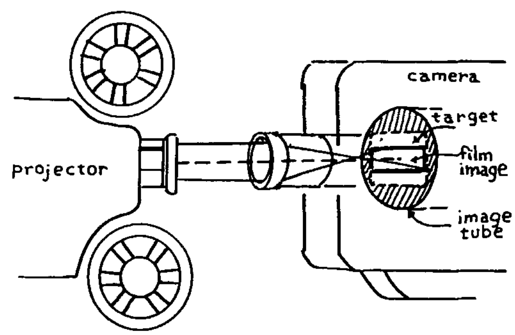
The problem we will discuss first and the one which creates the most controversy is that of aspect ratio. As mentioned earlier, in its original form a frame of film is of a different shape than a frame of television. Placing all of the information existing in a frame of film into a frame of television is rather like trying to place a rectangular peg in a square hole (Fig 4).



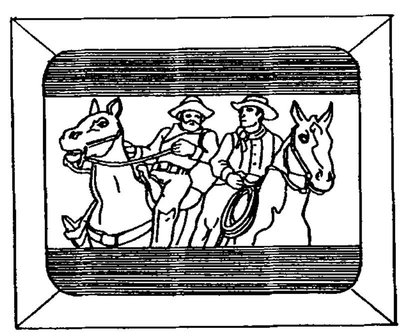
A number of methods have been developed with which to deal with this. Some more practical than others; all, however, require that the engineer performing the film to television transfer assume to take liberties with the program content. Usually, in the absence of the film's director and the TV technical director.

Herein lies the controversy; no known method of converting aspect ratio is wholly acceptable to all three (Director, Engineer, Technical Director). Current practice is limited to three techniques.

1. <u>Masking</u>: By effectively shortening the throw from the projector to the cine' camera, the film image is prevented from overflowing the image tube target area.



The result is, as shown in Fig. 6, a television picture which reproduces all elements of the original frame but, since it does not occupy the entire TV screen, is considerably reduced in size. This is doubly disagreeable in that we have taken a product intended for very large screen exhibition, reduced it to TV size, then reduced it further to accomodate masking.

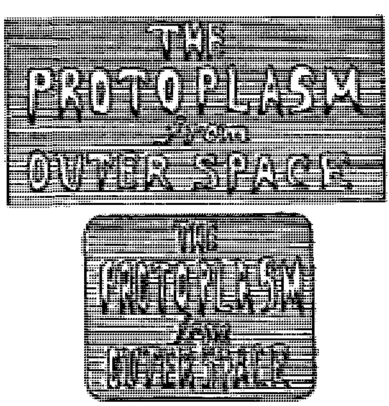


This technique while simple, diminishes the visual impact and causes small detail such as titles and credits to fall outside the resolution capabilities of the TV system.

2. Anamorphic: The term "Anamorphic" is applied to any optical system capable of compressing a normal image, in the case of TV horizontally and projecting it. FIG. 7.

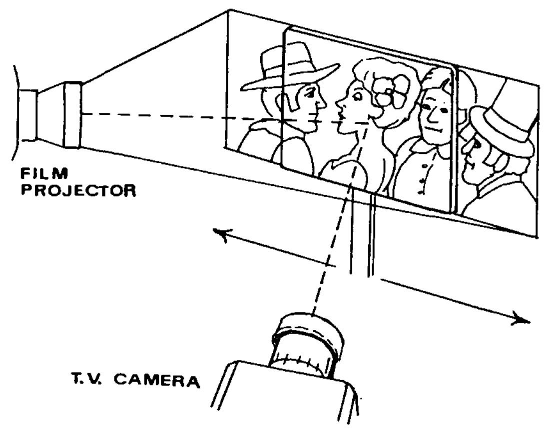
Again, this system accumulates all of the information in a given film frame for TV reproduction without loss of content. However, displaying a film in this manner would be well beyond the viewers ability to adapt. The result would be comical.

This technique does, however, lend itself well to the display of opening and closing credits and titles, appearing at the outside extremes of a film frame (FIG. 8) allowing them to fall within a TV frame's limits.



3. Pan and Scan: In this technique, a device, usually optical, in the film chain isolates a portion of the film image which corresponds to the TV aspect ratio. (FIG. 9) This device placed in the light path is moveable and under an operator's control.

A compromise by any interpretation, the pan and scan technique is both the most widely used by programmers and the least obtrusive to the viewer.



By being positioned horizontally, anywhere across the scene, the operator can select, for recording, that portion of the frame most necessary while losing the rest to overflow.

The receiver is rarely aware of the process or that more may be going on in a given scene than meets the eye, provided a deft and tactful hand is at the controller. Some disasters have occurred, however, where critical scene elements have been excluded; and while viewers are rarely aware of exclusions, directors are not.

Film directors are becoming increasingly dissatisfied with the pan and scan techniques and are understandably reluctant to leave such major creative decisions as scene content to a surrogate.

It remains, however, the only acceptable method in practical use today!

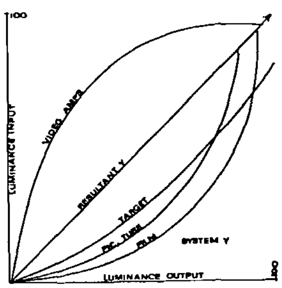
TRANSFER FUNCTION

Film generally exists in four generations:

1. Camera: The actual footage shot in production.
2. Lab: The intermediate stage used for producing protection copies etc.
3. Full Coat Magnetic: Magnetic sound track (oxideon film)
4. Print: For making copies or tape transfers

High quality tape transfers for television usually incorporates items 3 & 4 in a 35 mm format. The prevailing attitude for simplicity sake being; if a film (print) produces an acceptable image rendition in direct projection, it can be suitably transferred to television.

In order to reproduce the tonal gradations of the film image with fidelity, the transfer functions of the television system must be known. These non-linearities, in aggregate are known as system gamma. The controlling element in the system is the gamma or characteristic curve in the television receiving picture tube.



Most picture tubes exhibit a gamma other than unity. Therefore, low level input signals will cause output height levels to vary very little resulting in black compression. If similar transfer functions are present in camera target tubes and film emulsions, extreme black compression will result. This is often present in poorly transferred films as a loss of detail in dark or night scenes when viewed on television.

The condition if anticipated is correctable during the film to tape transfer process. Non-linear operation of the telecine' camera video amplifiers in a complimentary gain configuration will, at some sacrifice to video s/n ratio, neutralize compression yielding a linear transfer with gamma equaling one.

FRAME RATE

The final major dissimilarity evident in film to tape transfer is the difference in frame rate between the two mediums. Film is normally displayed at twenty-four (24) frames per second. Television (NTSC) operates at a thirty frames per second rate.

If no conversion is undergone, the reproduced television image will be rife with flicker and dark horizontal segments known as application bars, formed at the delta frame rate.

To eliminate these disturbances early film chain projectors were equipped with a clever shutter device; modern variations of which remain in use. The shutter operates on the principle that each frame of a television raster is composed of two _fields_ occurring serially at a 60 Hertz rate.

$$(60/24)2=5$$

If during the film pulldown each _two_ consecutive frames can be exposed to the camera target _five_ times, scanning unity can be achieved.

This is accomplished by placing a shutter drum with five correctly positioned openings between projector and camera. By rotating the drum at 720 RPM as the film is pulled down, the shutter will open three times during the first frame, two times during the second, three times during the third and so on. The result being each twenty-four frames of film is exposed to the TV camera 60 times; corresponding directly with the TV field rate.

CONCLUSION

Few products available to consumers today are produced with the emphasis on quality apparent in feature films. That quality is, however, highly susceptible to degradation when a film is not converted with the same professional care with which it was produced.

While none of the techniques described in this paper could be considered new, all play an important part in maintaining the quality of reproduction with which we are entrusted.

FREQUENCY ALLOCATION FOR DATA AND VIDEO

Rezin E. Pidgeon and David H. Slim

SCIENTIFIC-ATLANTA, INC.

INTRODUCTION

The use of broadband co-axial cable as a medium for data communications is a very attractive proposition. The "institutional" cables, available principally in the larger cities, are natural candidates for this service, and even those business users who have access only to "entertainment" cables will find that, in most cases, a sufficient amount of unused bandwidth is available to carry a large number of data channels. However, the implementation of these services has proceeded in a most desultory fashion, and one technical reason for this is the lack of precise knowledge, both theoretical and empirical, of those characteristics of the broadband medium which are likely to affect the transmission of data and which may cause reciprocal effects upon video signals.

While it is not possible to exactly characterise all cable systems, bearing in mind the diversity of topography and gross performance specifications, some general theoretical and practical observations can be made here which may smooth the way for a more enlightened approach to this application of cable TV networks.

TOTAL AVAILABLE BANDWIDTH

CATV manufacturers are now offering distribution equipment with an upper frequency limit of 450 MHz. Equipment capable of handling signals up to 400 MHz has been available for approximately 3 years from most manufacturers and, based on an analysis of recent shipments, accounts for some 70% of new system construction. However, if the current state of the U.S. CATV industry is analyzed in terms of the total number of systems currently in use, it will be found that by far the majority are using equipment with an upper frequency limit of 216 or 270 MHz. The fundamental requirement imposed on a CATV system by interactive data services is the availability of 2-way operation, and it is known that only a minority of the 216 and 270 MHz systems possess or can be adapted to provide 2-way transmission without complete replacement of amplifier stations. These types of system, therefore, will not be discussed here. In mitigation, it must be pointed out that these systems are to be found principally in rural or suburban environments (a circumstance which follows logically from the historical development of Community Antenna T.V.) and, therefore, may not be counted as major candidates for business data communications services.

Potential available bandwidth in the remaining systems (300, 330, 400 and 450 MHz) for data communications purposes is determined by the number of channels currently unused, and by the upstream capacity. While there is universal agreement on the frequency limits of the sub-split format, the situation with regard to mid-split and high-split is not so well defined, and it is advisable for the would-be data user or equipment supplier to determine exactly the upstream and downstream cut-off frequencies in the system under investigation.

Even when excess bandwidth in both upstream and downstream paths is available, the locations of the unused downstream channels can place a constraint on the selection of data communications equipment. Some modem suppliers offer a limited choice of carrier frequencies, and there have been moves to specify "paired" transmit and receive channels (1). While these pairings represent a much-needed standardization, they can cause conflict in both sub-split entertainment and institutional systems. A CATV system operator is understandably reluctant to re-locate existing T.V. channels, and, therefore, should examine proposed data modem frequency allocations carefully.

LIMITATIONS DUE TO NOISE

The problem of noise in the upstream signal path is universally acknowledged, if not thoroughly understood. Analysis has shown that there are seven basic mechanisms by which noise can enter the upstream path:

1. Ingress

2. Conducted and radiated emission from switching power supplies.

3. Thermal noise crossover from downstream amplifier.

4. Intermodulation crossover from downstream amplifier.

5. Intermodulation generated at non-linear connections.

6. Intrinsic thermal noise in reverse amplifiers.

7. Intermodulation generated in reverse amplifiers.

Of these, only Items 3 and 6 can be subjected to simple statistical analysis and used to produce an estimate of total white gaussian noise (WGN) arriving at the system headend. (This noise is also the only parameter which can be handled by simple mathematics to determine the anticipated bit-error-rate (BER) for a given modem modulation scheme, as will be shown later.) It should also be noted that emission from switching power supplies (Item 2) can generally be ignored.

The other noise sources, representing discrete interfering signals in the reverse path, are not amenable to the same statistical treatment, and vary widely from system to system. However, the conclusion which can be drawn from these facts, and which is of greatest interest to the system operator, is that the intrinsic thermal noise processes are predictable yet unavoidable, while the discrete interfering processes are unpredictable yet avoidable. (That is, their short-term characteristics are not absolutely determinable a priori.) The theoretical upper limit of reverse system performance can therefore be estimated in advance, and can form the basis for a discussion whether or not to proceed with data communications services.

It can be shown that the aggregate thermal noise per 4 MHz band, N_T, arriving at the system headend, is given approximately by:

$$N_T = N_I(\Sigma^{n} f + m) \text{ mV}$$

where N_I is the minimum noise level in a 75 ohm system, n is the total number of active devices in the reverse path, m is the number of active feeders, and f is the noise factor of a reverse amplifier, corrected for degradation due to thermal noise crossover.

This will yield a result in the more familiar units of dBmV if written:

$$N_T = -59 + 20\log_{10}\{\sqrt[2]{n}.10^{(\frac{f}{10})}+m\} \quad \text{dBmV}$$

where F is the noise figure in dB. ($F = 20\log_{10}f$).

For a small system of 18 trunk amplifiers and 23 line extenders in 10 feeders, assuming F = 10 dB, a value for N_T of -29.38 dBmV is found, which agrees well with experimental results (see below).

When discrete interfering signals are analyzed empirically, decisions can be made regarding the cost and complexity of attempts to reduce their effects, if indeed such measures are necessary. These decisions will also be influenced by a knowledge of a given modem's ability to ignore adjacent or in-band interference. (See below, "Characteristics of Broadband Modems".)

FIGURE 1

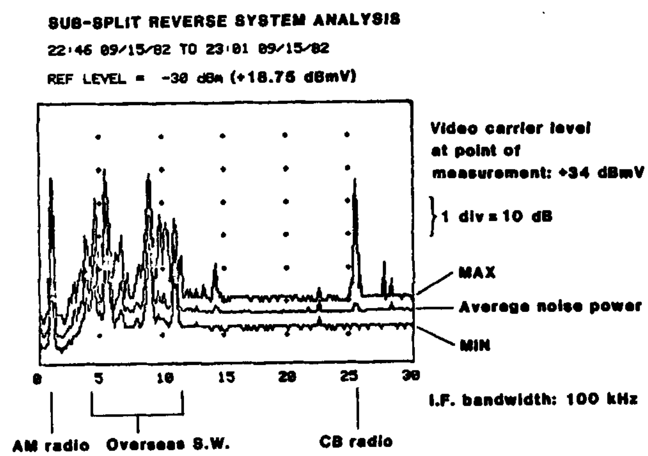


Figure 1 shows the results of measurements on a typical small distribution system, during a period of moderate interference. Measurements like this, taken over a 24-hour period, provide certain valuable facts about the system:

1. The average WGN level is -28 dBmV.

2. The maximum level of any interfering signal in the 24-hour period was 0 dBmV.

3. A band of frequencies between 15 and 25 MHz is the most noise-free, with a maximum interfering carrier level of -10 dBmV.

(Note: The apparent noise levels designated "MAX" and "MIN" in Figure 1 are produced by the sampling system which recorded the results. They can be regarded as defining the instantaneous maximum and minimum excursions of the noise signal.)

As will be discussed later, this system can accommodate data transmission from modems utilizing high-level modulation techniques.

CHARACTERISTICS OF BROADBAND MODEMS

The function of a broadband data modem is to provide the interface between data terminal equipment and the R.F. transmission medium (2). For this purpose, there are a myriad of possible modulation and detection schemes differing in efficiency, complexity and performance. The various modulation schemes include mutli-level amplitude modulation ("amplitude shift keying"), multiphase modulation (e.g. QPSK) and frequency-shift keying (FSK). Also, for a given type of modulation, different techniques for demodulation and signal processing exist. Thus, a comparison of such diverse systems in a meaningful manner is not simple. Therefore, it seems prudent to eliminate from our discussion those modems which utilize relatively simple processing and low efficiency modulation techniques, and which are more tolerant of adverse CATV system conditions. Instead, we will examine a high-speed (1.544 Mbps), high-efficiency device using 16-level Quadrature Amplitude Shift Keying (16-QASK). (3)

In this system, the binary data is sampled in groups of 4 bits, encoded and transmitted as 16 possible phase-amplitude states of the modulated carrier. The symbol (baud) rate is 386 KHz (2), and filtering confines the transmitted spectrum to a band somewhat less than 750 KHz wide. Thus, eight data channels running at 1.544 Mbps can be placed in a 6 MHz T.V. channel. Figure 2 shows the spectrum of the 16-QASK transmission.

The immunity of a given modem transmission to gaussian noise is ultimately defined by the manufacturer's specification, and it is generally unsafe to predict actual performance from theoretical considerations, since these take no account of implementation losses in the encoding, modulation, demodulation and decoding processes. However, for the sake of completeness, we have included Figure 3, which presents the ideal probability of error, Pb, to be expected for a given signal-to-noise ratio. The parameters Eb and No are defined:

Eb: energy per bit

No: rms noise power measured in a 1 Hz bandwidth.

In order to achieve $Pb = 10^{-9}$, the ratio Eb/No must be 19.36 dB. To convert this figure into the conventional S/N parameter, where N is the rms gaussian noise measured in a 4 MHz bandwidth, and S is the average signal power of the data transmission, we write:

$$S/N = 10\log_{10}(10.^{\frac{Eb}{No.10}} \times 1.544 \times 10^6) - 10\log_{10}(4 \times 10^6) = 15.23 \text{ dB}$$

Now, if S is 10 dB below video carrier level C, the required system carrier-to-noise ratio is 15.23 + 10 = 25.23 dB.

FIGURE 2

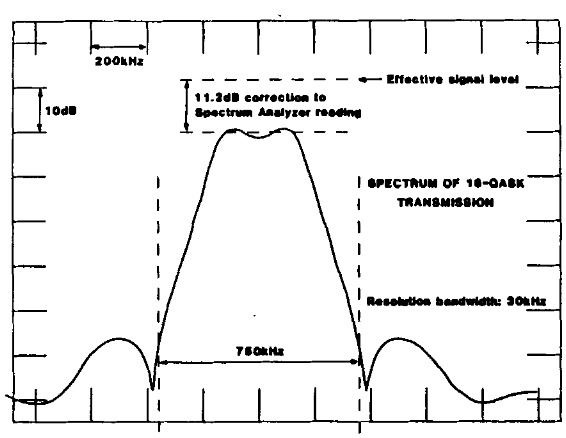
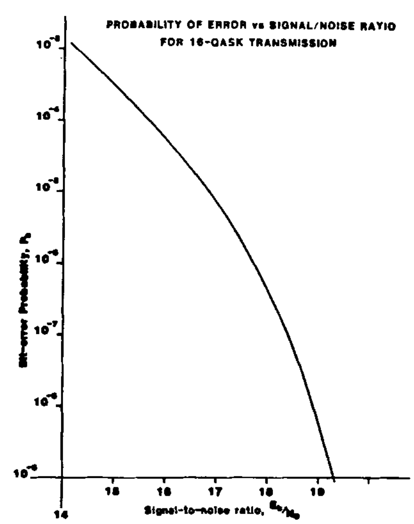


FIGURE 3



As stated above, this figure represents an ideal, and in practice a value of 33 dB is found to be more realistic.

In order to communicate between two widely-spaced points in a CATV system, a data transmission must travel via the upstream path to the headend, where it will be processed by a frequency up-converter ("translator"), and then via the downstream path to its destination. Therefore, the total available C/N must be calculated taking this route into consideration. If we assume that the one-way C/N is at its worst-case FCC limit of 36 dB, and the translator has a noise figure of 7 dB, then the overall path C/N will be approximately 33 dB. Hence, it can be seen that the practical requirement of 33 dB C/N for 16-QASK transmission is met by a system operating at the minimum permissible performance. If a 6 MHz channel is fully loaded with 8 data signals using the modems described above, when the average data signal power is 10 dB below video carrier level, the total power in the channel will be 1 dB below TV channel power.

To determine the ability of the modem transmission to ignore interference from discrete carriers, a series of tests was conducted in which the BER of a transmission was monitored as a carrier was added to the RF signal at varying levels and offsets from the data signal center frequency. At the same time, white noise was added to the transmission, so that the system was operating with a carrier-to-noise ratio (video) of 33 dB: the worst-case condition.

FIGURE 4

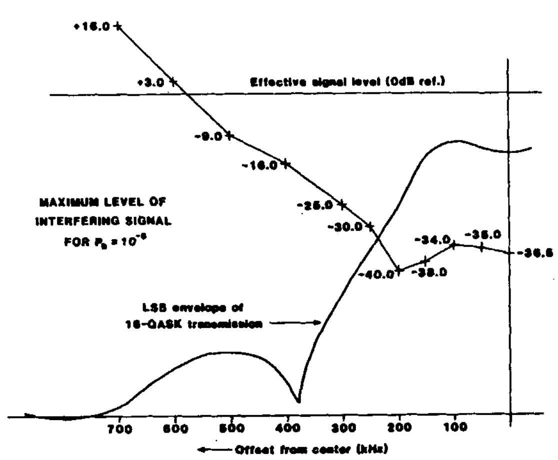


Figure 4 shows the maximum permissible interfering carrier level for a BER of better than 1 in 10^8. Note that the true power of the data transmission is obtained by applying a correction factor to the level observed on a spectrum analyzer. The reason for selecting a threshold of Pb = 10^{-8} rather than 10^{-9} is one of simple expediency. To detect one bit-error in 10^9 bits requires a measurement interval of approximately 11 minutes, which must be repeated several times to obtain a statistically meaningful sample. If even one error is detected during these intervals, the level of the interfering carrier must be reduced fractionally, and the measurement re-started.

From these results, it can be seen that the 16-QASK transmission will tolerate an interfering carrier of equal amplitude at a separation of 600 KHz, while still maintaining a BER of 1 in 10^8. To relate this to a real environment, we recall that in the conclusions drawn from Figure 1, we noted that the maximum interfering carrier level in the interval 15-25 MHz was -10 dBmV. With a data transmission at 10 dB below video carrier level (34-10) dBmV, the interfering carrier proach within 250 KHz of the data transmission center frequency, before increasing the BER above 1 in 10^8.

We conclude that the potential available bandwidth must be carefully monitored over a period of time (preferably 24 hours) and the maximum interfering carrier level compared to the modem manufacturer's specifications. This is an unavoidable precaution, bearing in mind the unpredictable nature of signal ingress. It should also be stressed, however, that this type of interference can be reduced, assuming a thorough understanding of the cable system, and adequate system maintenance.

CONSTRAINTS IMPOSED BY HEADEND PROCESSING

As described above, the data signal will in most cases be routed through a frequency up-converter (translator) at the CATV system headend. This conversion will usually take place in bandwidth increments of 6 MHz, but it must be borne in mind that the effective conversion bandwidth must in reality be less than this ideal, due to the nature of practical filters and the need to reject adjacent 6 MHz channels. It is a common practice to use a standard signal processor for data translation, and these devices typically will have a bandwidth slightly less than 5 MHz at the half-power points. Furthermore, the passband will not be symmetrical with respect to the 6 MHz channel limits. The number of potential data signals lost due to this restriction will, of course, vary with the modem transmission bandwidth: in the case of the 16-QASK transmission described above, the number of data signals per available 6 MHz channel will be reduced from 8 to 6.

The frequency stability of the translator is also an important consideration: the maximum possible long-term drift should be compared to the received frequency "window" as specified by the modem manufacturer.

CONCLUSION

Much work still remains to be done in the characterization of CATV systems for data transmission. We have not yet reached the point at which accurate performance predictions can be made for a wide variety of systems, as is common place with video-only installations, when dealing with very large numbers of modems and volumes of traffic. Such predictions will be possible, we feel, in the very near future: manufacturers are now performing the experiments which will reveal in detail the performance of CATV systems under varying loads of mixed video and data traffic. In addition, as the demand for business data communications using alternative transmission media increases, the body of theoretical and empirical knowledge will grow and contribute its share to a more exact understanding of the field.

In the meantime, we are confident that the information which has been presented here will provide reasons for a high degree of optimism in beginning the excursion into a new area of CATV system applications.

REFERENCES

1. IEEE Project 802, Local Network Standards Committee, Status Report. April, 1982.

2. "Data Communications Via Broadband Cable: Definition of Terms". Scientific-Atlanta Applications Note AN0582-01. (Slim, David H.)

3. "Bandwidth Efficient, High-Speed Modems for Cable Systems". Scientific-Atlanta Applications Note AN0582-01. (Klare, Stephen W. and Rozmus, J. M.)

HEADEND TECHNIQUES FOR REDUCING DISTORTION IN DISTRIBUTION SYSTEMS

William T. Homiller

GENERAL INSTRUMENT JERROLD DIVISION

The rate of increase in distribution system bandwidth and signal loading has exceeded the rate at which amplifier noise and distortion performance has been improved. This has resulted in some dependance upon headend based techniques, such as harmonically related coherent picture carriers. The continuation of this trend demands additional techniques to supplement the development of improved amplifier technology.

A headend system capable of coherent carrier, sync suppression and synchronized video operation was constructed. The hardware implementation of each method is described. A representative distribution cascade was used to determine the effect of each headend technique on system distortion performance. Both subjective and measureable effects were investigated, with the various techniques were evaluated individually and in combination.

INTRODUCTION

Since the development of distribution systems with 400 MHz bandwidth, the demand for system channel capacity has tended to increase more rapidly than basic amplifier distortion performance. It appears to be fundamental to the nature of the amplifying devices that distortion performance deteriorates as frequency increases. This implies that the conflict between increased bandwidth and distortion performance will worsen.

Where system distortion performance is insufficient, an alternative is to employ special headend signal processing techniques which cause the subjective visibility of distortion to decrease. Coherent carrier headend systems represent one such technique. Specific implementation of this technique, such as Harmonically Related Carriers, are already widely accepted as a basis for expanded bandwidth distribution system design. The improvement in apparent amplifier distortion performance permitted the design of practical systems with capacitance of 50 or more channels per cable. Since the development of systems with 500 MHz or greater bandwidth appears inevitable, new techniques are required to allow the transmission of 75 or more channels per cable.

Two headend signal processing techniques which could permit increased system loading are all channel sync suppression and all channel video synchronization. The hardware to implement these techniques already exists so the assessment of their value for distortion reduction becomes an entirely practical matter.

THE AMPLIFIER CASCADE

The results reported herein were obtained from the traditional method that is used to evaluate the effect on system performance of any change in circuit or system design, or change in environmental or signal conditions; that is, the impairment to high quality video signals is determined by observing changes in picture quality after the signal has passed through a representative amplifier cascade. The actual cascade consists of sixteen trunk amplifiers with equal cable spacing, followed by a distribution line consisting of a bridger and two line extender amplifiers.

HEADEND SYSTEM DESIGN

A headend system used for such an investigation has to perform the usual function of producing a combined RF output of up to 65 channels suitable for driving a distribution trunkline. In addition, several unconventional features are required. These include the ability to switch rapidly between Harmonically Related Carrier (HRC) operation and non-coherent operation; the means to switch instantly from synchronized to non-synchronized video modulation and a facility to select horizontal sync suppression and vertical sync suppression independently in any combination, including no suppression.

The system was constructed from standard headend products to minimize construction time. The hardware is organized into three sections for flexibility in program switching and special function control. A block diagram of the complete test headend system is shown in Figures 1, 2 and 3.

The Video Source Section

It is assumed, when simulating the signal conditions of a distribution system, that video program content is not repeated. Since it is not practical, in the laboratory, to produce a separate video program for each RF channel, it was decided that 20 programs, where no program would appear on more than 3 channels, was an acceptable compromise between system complexity and realistic conclusions. The number of programs cannot be reduced arbitrarily because the subjective visibility of distortion products is affected by video duplication.

The required 20 video program sources consist of 10 satellite receivers, 9 off-air demodulators and an EIA standard color bar generator. The video output of each source unit is applied to a video synchronizer so that all 20 video signals can be synchronized when required. The color bar video standard is supplied to all of the synchronizers as a timing reference. By disconnecting the reference video the synchronizers switch automatically to bypass mode and non-synchronized operation results. The synchronizer outputs are applied to a video patch panel.

The Video to I.F. Section

This section includes standard modulators with I.F. output and Scrambled Service Encoders to provide for suppressed sync operation. The standard encoder was modified to permit independent selection of horizontal or vertical sync suppression. The scrambling system normally increases the peak carrier level by 3 dB during scrambled operation, so this mode was made programmable as well. When all channels are scrambled, the 3 dB boost is equivalent to raising the headend system output level by 3 dB.

Therefore, this feature was deactivated throughout this test series. The addition of a simple interface allows external control of the sync suppression mode of all 20 intermediate frequency (I.F.) sources from a single switch. The output of each modulator is split 3 ways and connected to an I.F. patch panel. The patch panel connections determine the channelization of the 20 sources.

The I.F. to Channel Section

This section contains 58 standard phaselocked capable I.F. to channel converter modules and associated I.F. phaselocked circuitry. Switching facilities allow the replacement of the normal I.F. input of any converter with an unmodulated carrier and the elimination of any channel from the combined output. HRC operation is obtained by phaselocking all converters to a common reference comb. Non-coherent operation is obtained by disconnecting the reference comb signal whereupon the converters switch automatically to crystal controlled operation. The converter module R.F. outputs are combined with 8-way couplers as in a typical CATV headend to provide an output to the cascade under test.

A Review of Coherent Carriers

Coherent carrier techniques, exemplified by HRC, are already used widely with systems designed with a capacity of 50 or more channels. Although HRC is not considered herein as a new method, it will be seen that the effect of the new techniques being investigated can differ from HRC to non-HRC conditions. In reviewing the principle of HRC, we recall that the intermodulation products of two or more picture carriers are caused to be coherent with any given picture carrier. This makes the carrier intermodulation products subjectively invisible and leaves the associated modulation sidebands as visible interference. It is generally held that this results in a subjective reduction of distortion levels of 10 decibels and allows amplifier output levels to be increased by up to 5 decibels.

ALL CHANNEL SYNC SUPPRESSION

The cascades under study are limited in output level by third order intermodulation distortion. When the system is without the benefit of special headend techniques, and the amplifier level is raised to produce visible degradation, the familiar "composite triple beat" effect is seen. This appears as a generally random noise-like pattern with horizontal streaking. At times local concentrations, usually in the form of sliding bars, will be seen. These are associated with energy peaks of the carriers that are generating the triple beats. The energy peaks occur during the synchronizing pulses of the video signals that are modulating the distortion producing carriers. When these peaks coincide in time for several carriers, a worst case concentration occurrs which determines the threshold for perceptable distortion.

When all-channel sync suppression or scrambling is activated, the carrier levels are reduced by 6 dB during horizontal and vertical sync intervals. This eliminates the energy peaks described above and results in a more uniform and random triple beat pattern. This suggests a reduction in the worst case perceptability of this distortion and an attendant increase in amplifier output level.

When the headend system is switched to HRC mode the carrier triple beats are no longer seen. As the system level is increased, the video modulation components of the distortion producing carriers become visible. Typically, the most perceptable aspects of this form of distortion are sliding vertical or horizontal bars associated with the synchronizing information of the video waveform.

When all-channel sync suppression is employed under HRC conditions, the perceptability of the sync bars is reduced such that they do not predominate. Major picture elements in the distortion producing channels, such as a row of large white characters, are seen to be as visible as the sync bars. The constant horizontal or vertical sliding of these frames continues to increase visibility. Again, this suggests that some increase in amplifier level should be possible for just perceptable distortions.

VIDEO SYNCHRONIZATION

Activating video synchronization causes the synchronizing information in the video waveforms of all channels to be time coincident. This means that any elements of distortion that are associated with the sync pulses of the distortion producing channels will occurr during the horizontal and vertical blanking portions of the picture being viewed and will not be visible. The sliding frame effects are also eliminated by synchronization. This combination of two beneficial effects suggests that synchronization may be subjectively more beneficial than sync suppression.

In the non-HRC situation the subjective result is generally similar to that obtained with all-channel sync suppression: the composite triple beat pattern appears to be uniform without the barlike concentrations.

Under HRC conditions the vertical and horizontal "sync bars" are not seen and the only background motion is that caused by moving elements in a particular distortion producing channel.

TEST RESULTS

Initially, the distribution portion of the cascade was operated with bridger and line extender output levels, relative to the trunk amplifier output levels, at typical system values. It was found, however, that when system levels were raised above the perceptible distortion threshold with the above techniques used together that the system no longer exhibited "linear" behaivour. Direct measurement of third order distortion showed that the incremental ratio of distortion to signal level was about 5 to 1 rather than the 3 to 1 ratio expected from a normally behaved system. Under practical conditions this would not occur because no system would be designed to operate with perceptible distortion. Instead, a typical system might operate 3 dB below this point.

Since it is necessary to produce visible distortions in order to make subjective judgements, it was decided to reduce the distribution signal level enough to obtain perceptible distortion under all conditions without producing amplifier compression. The bridger amplifier gain was reduced to produce a distribution level of 8 dB above trunk level. The average trunk level at which distortion was just perceptible on channel 51H was 35.5 dBmV, corresponding to 44 dBmV distribution level.

Twelve viewers participated in the subjective tests. Each viewer used his own interpretation of "just perceptible". The actual trunk system level at which "just perceptible" degradation was seen was recorded for each headend operating mode. The group was retested on four occasions to allow for program related variations and human consistancy and the total data was averaged. The averaged results were then normalized to a zero value for standard conditions. The resulting numbers represent the change in system level, compared to standard conditions, that produced equally perceptible distortion for each of the three headend techniques individually and in combination:

SYNC SUPPRESS	VIDEO SYNCH	STANDARD	HRC
OFF	OFF	0.0 (REF)	+5.1 dB
ON	OFF	+1.6 dB	+6.7 dB
OFF	ON	+1.2 dB	+7.2 dB
ON	ON	+1.7 dB	+7.6 dB

Additional observations were made on channels 4, 18, 11 and 38 to make certain that the channel 51 results above were not anomalous. The absolute levels at which distortions were seen increased, as expected, with decreasing frequency, but the relative effect of the various headend techniques was essentially the same as seen at channel 51.

A LIMITATION OF CLASS 1 CHANNELS

Current FCC regulations prohibit the scrambling of class 1 broadcast channels. Leaving these channels unscrambled would reduce the subjective benefit of the full system sync suppression technique. This compromise might be minimized by placing such channels at the system's lowest frequency assignments. On the assumption that 12 class 1 channels would be typical for a large system, the practicality of this approach was tested by reconfiguring the headend system such that lowband channels 2 through 6 and highband channels 7 through 13 were never sync suppressed, but could be video synchronized. The remaining 46 channels were operated as described above. The average threshold for "just perceptible" triple beats with twelve viewers was 35.6 dBmV, vertually the same as the first configuration. After normalization, as above, the following results were obtained:

SYNC SUPPRESS	VIDEO SYNCH	STANDARD	HRC
OFF	ON	0.0 (REF)	+5.6 dB
ON	OFF	+0.9 dB	+6.6 dB
OFF	ON	+1.2 dB	+7.5 dB
ON	ON	+1.7 dB	+8.1 dB

These results are sufficiently similar to those obtained with full sync suppression to suggest that such a compromise could be made and still obtain most of the benefit of that technique.

SUMMARY AND CONCLUSIONS

Harmonically related carrier headends have provided a practical method for increasing system capacity by making the triple beat products of the picture carriers subjectively invisible. Under HRC conditions, the limitation to amplifier output levels is the subjective visibility of the video modulation sidebands of the third order distortion products. This suggests that further increases in system capacity could be obtained from additional headend techniques that would reduce the perceptibility of the distortion sidebands. All channel scrambling and video synchronization are two techniques which should provide this form of improvement. These techniques were evaluated subjectively by a limited group of expert viewers using a test headend system that could be switched between standard, HRC, all-channel scrambling and synchronized video modes. Operating the system in HRC mode alone allowed a 5.1 dB increase in amplifier level, a value that is consistent with earlier results. All-channel scrambling permitted an average increase in system levels of 1.6 dB above that enabled by HRC. Video synchronization produced an increase of 2.1 dB beyond that of HRC. Both techniques operating simultaneously allow a level of 2.5 dB above HRC. If the use of scrambling was excluded from class I channels, indications are that most of the distortion benefit would still be obtained, provided that the Class I programs are assigned to channels at the low end of the system spectrum. Video synchronization provides a greater reduction in distortion visibility, but has a very high hardware cost. The synchronizers used for these tests cost about 8900 dollars. The cost of this equipment has dropped from over 25,000 dollars in the last three years and would certainly continue to drop if the synchronization technique were used on a large scale.

Since the data presented herein represents only a single system configuration and was obtained from a limited number of expert viewers, the results presented must be considered preliminary. However, the results serve as useful indicators of the relative merit of each technique.

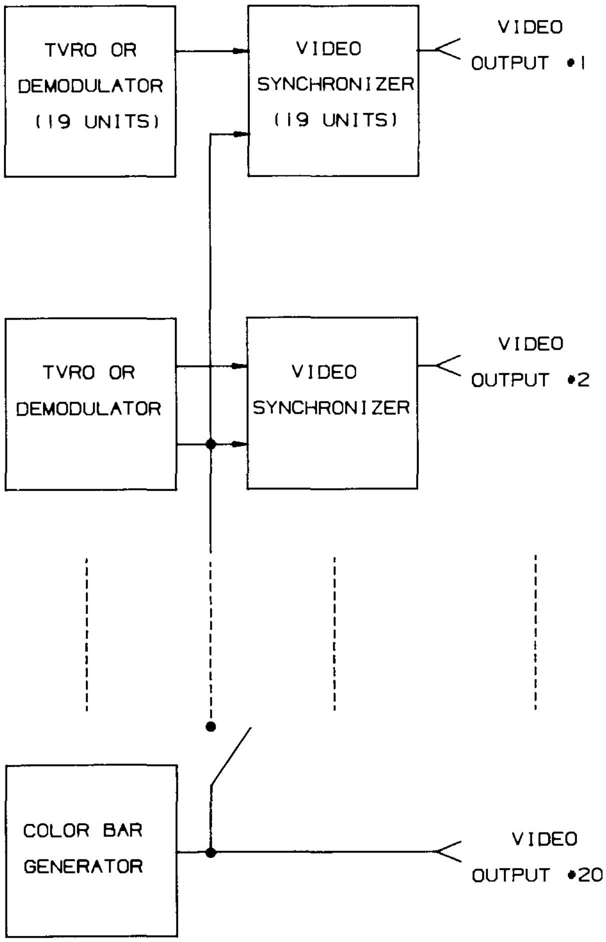


FIGURE 1.

VIDEO SECTION

TEST HEADEND SYSTEM

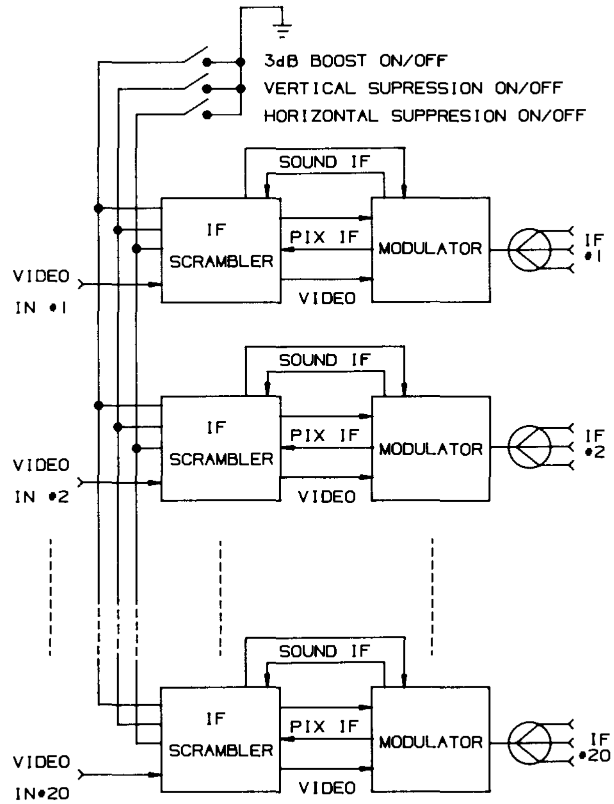


FIGURE 2. VIDEO/I.F. SECTION

TEST HEADEND SYSTEM

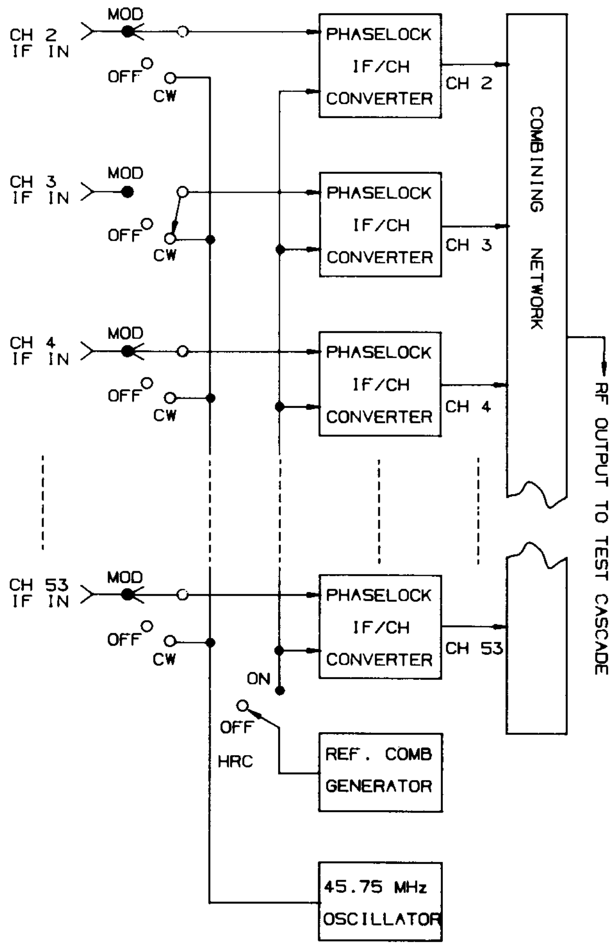


FIGURE 3.

IF/RF SECTION
TEST HEADEND SYSTEM

HI-OVIS IN NEW MEDIA ERA

Masahiro Kawahata

VISUAL INFORMATION SYSTEM DEVELOPMENT ASSOCIATION

ABSTRACT

Tremendous amounts of effort have been made in developing information systems that play an essential role in supporting an information-oriented society, and the use of such systems has become quite common for the general public today. We already enjoy various advantages from some of the more general, public systems in our daily life, such as seat reservation systems for public transportation, automatic ticket issuing, examining and collecting systems, cash dispensing systems at banks, and stock information systems.

Conventionally, there have been two types of information media in our daily life; mass media, such as newspapers, magazines, radio and television, and more personal media, as represented by telephones and letters. However, as a result of remarkable progress in modern technologies such as data processing, telecommunications (especially fiber optics and satellite telecommunications), and image technologies (such as video disks), new types of communication media have been developed and ways to put them to actual use are being studied from extremely realistic perspectives.

This report concerns the current status of Hi-OVIS (Highly Interactive Optical Visual Information System) which has played a leading role in the development of information service systems in Japan, and studies being made regarding its new role in the new media era, as well as future plans for further development.

1. PROJECT PHASE I (1972 - 1982)

1-1 Development schedule

Studies for this project were launched about 1972, and we began to draw up plans for the project in 1976.

Plans were formed on the basis of the most advanced technologies then available and revolutionary concepts, and we began providing services in July, 1976.

Hardware technologies have made significant progress since then, but the design concepts and functions of our system are still unmatched today by anyone else. We are making the most advanced experiments in our project, which is capturing the attention of many people as we enter a new media era.

1-2 System design concept

According to the objectives determined for Hi-OVIS development, there are three features that this system must provide, as summarized below, with respect to information to be handled in such a system;

1) The flow of information under this system must not be restricted to one direction (from the sender to the receiver). Instead, it should be bidirectional, going back and forth between the sender and the receiver.
2) The source of information should be such that the receiver can choose the particular information he wishes to receive.
3) Information must be in different forms, such as voice, data, images, etc.

This system is quite unique in three particular aspects.

1) It employs fiber optic transmission technology on a large scale.
2) It is an individual distributing system with subcenters between the center and individual subscriber monitors.
3) It is a two-way transmission system containing a TV receiver, camera, microphone and keyboard installed in each subscriber's home as well.

These unique features make it possible, unlike other information systems, to provide various types of programs for the subscribers and also to make such programs with the monitors.

1-3 System configuration

A basic system configuration comprises a center, sub-centers and home terminals connected to each other via fiber optic transmission lines, as shown in Fig. 1. Typically, instruction data is transmitted from the keyboard of a subscriber's home terminal unit on the upstream lines to a sub-center, specifying a specific program of particular interest that the subscriber wishes to receive at home. A video switch in the sub-center is turned on while it is communicating with the center to establish a line between the center and the subscriber's home terminal. The center then interprets the instruction data and controls a particular information source that has a program such as requested, and the program is sent to the subscriber requesting the program.

The number of sub-centers varies according to the need of individual subscribers. In an experimental system currently installed in Higashi Ikoma, sub-centers are located within the center building since subscriber homes are distributed within the vicinity. The scheme of the experimental system is shown in Fig. 2.

1-4 History of software development

The Hi-OVIS contains 29 service channels as listed in the table I

In planning programs and information services within the software availability shown above, experimental operation for Phase I was carried out in four developmental stages.

Stage 1 (July, 1978 - June, 1979)

The primary purpose of Stage 1 was to establish a firm foundation for the experimental operation itself.

Stage 2 (July - September, 1979)

System functions, especially the two-way transmission function, were studied from various angles.

Stage 3 (October, 1979 - March, 1980)

Efforts during this period of development were focused on system applications, especially on how to invite local residents to participate in the operation of the system.

Stage 4 (April, 1980 - March, 1983)

The following program development was made during this period, in order to pursue the commercial possibilities of the Hi-OVIS project.

- Programs for Pay TV such as educational programs and movies.

- Time Leasing. In this service, known as Info-mercial Program Service, time was leased in blocks of one hour at a time to private companies. Through series of trials, this service proved to be the most successful area of the completely bidirectional function of the system, and both the sponsoring companies and the monitors are very keen to see this type of service continue.

- Information Gate Way. This is a news service based on real time information sent from news agencies and then put on the system in an unedited form. Audience ratings went up significantly after important events of a serious nature or of special public interest.

1-6 Subscriber opinion research

Questionnaires are sent to the subscribers each year in order to evaluate the experiment from various aspects. According to our latest survey, more than 95% of the present subscribers wish to continue subscription of the services. Those who do not wish to continue include people who cannot continue for reasons beyond their control, such as relocation in their companies. The high percentage as verified in our surveys proves that the system is highly valued by the subscribers.

The popularity of the services being provided under the experimental operation is determined significantly by occupancy, as well as audience rating. Occupancy is defined as follows;

$$\text{Occupancy} = \frac{\text{No. of subscriber TV sets}}{\text{No. of switched on TV sets}}$$

Uniquely, the occupancy rating of original programs is extremely high in the Hi-OVIS project. Unlike commercial TV programs or newspapers, what the subscribers to the Hi-OVIS services look for are mainly,
1) Local community information,
2) Consumer and living information, and
3) Educational and cultural information.

2. PROJECT PHASE II (1983 - 1985)

In Project Phase I, we have proved that a completely bidirectional system, including image signals, was not only technically possible but also useful in matching people's needs for information.

We will now outline the position of Hi-OVIS as we see the situation in Japan, and also summarize our plans for Hi-OVIS in Phase II.

2-1 Current status of CATV in Japan

Large scale, sophisticated CATV systems have not developed in Japan, mainly because (1) CATV systems were originally designed as a remedy for poor reception of radio wave, and (2) in large cities such as Tokyo and Osaka, as many as seven channels are broadcast through-the-air from early morning (6:00AM) till past midnight (0:30AM).

Recently, however, private railroad companies, trading companies, distribution industries and advertising agencies have begun preparations for installing CATV facilities with bidirectional functions, and finance, press and publising companies have shown interest in taking part in such plans.

In addition, the Ministry of Posts and Telecommunications is testing Videotex (called CAPTAINS in Japan), and TV companies have plans to start Teletext broadcasting.

When these plans become more practical, they will not only contribute to the diversification of selective means for information, but also affect industrial structures in Japan as well as people's daily lives, as such plans, when put into practice, will inevitably establish systems for home banking, home shopping, remote medical services and tele-education. Tele-education, especially, will bring help to many people who are unable to go to school.

The Japanese government, fully aware of these plans and possibilities, is planning to establish relevant policies for such undertakings, and some ambitious guidelines are expected in the near future.

2-2 Hi-OVIS Project Phase II

Based on the results of our development in Phase I, we hope to launch new efforts for cabled information systems for the new media era.

2-2-1 Application of televoting function

We are planning to develop systems capability stressed on software for teaching, especially in skill training, since televoting function can be used also for the instructor to evaluate individual students' understanding as if the teacher and the students were in a man-to-man situation. Communication between instructor and students will be established by means of camera and microphone hardware located in their homes as part of the bidirectional image and sound system.

It will be quite feasible to develop these concepts for practical CAI implementation when appropriate software becomes available.

Another application based on the televoting function is test marketing of commercial goods, and this application will be described later under Channel Time Leasing.

Use of the televoting function of the system can become a source of income for the CATV operator since he can charge certain fees to the subscribers who receive educational and other programs that provide benefits to them, or to the sponsors of test marketing and other programs.

The most important strength of CATV systems is the fact that these programs can never be provided by mass media.

2-3 Hi-OVIS connection with other information system

There can be two types of environments that require such interface efforts.

1) Networking CATV systems with Hi-OVIS

Japan is being decentralized, it is said, in reaction to the stereotyped emphasis on centralized social systems in the past, and there has been a strong move for the unique development of local areas. Different communities are making original efforts toward such decentralizing goals throughout the country. The results of such developments are exchanged among different communities to start new efforts or modify their current activities accordingly.

These communities often face common problems, and it can be extremely stimulating for members of such communities to get together and share their problems, experiences and views.

Consequently, we believe that our Hi-OVIS can be connected to other CATV systems to provide opportunities for the members of both systems to exchange their views on any subject they wish.

2) Connecting Hi-OVIS with other data base systems

During last year, latest news from news agencies was broadcast through Hi-OVIS in the form of characters information on the TV screen on a regular basis. This year, we plan to advance further, and at least classify original news into specific different categories so that the subscribers can retrieve latest news in the form of conveniently suited.

On-line data base systems have become common in Japan recently, and we have also began studying different ways to link our system to such data base systems so that the subscribers can access such systems freely.

2-4 Channel time lease

Several feasibility studies were made last year in which our channels were offered to private companies on a time (hourly) basis, and the experiment proved very successful. Representatives of these companies spoke on different subjects in our experimental programs, and subscribers at home put questions to the speaker, or asked the speaker for more explanation on specific topics. They also gave their own views on these topics. This is not possible on ordinary through-the-air TV programs. Subscribers were well satisfied with our experimental programs, as were the speakers representing the companies, who found the occasion much meaningful, since subscribers often pointed out to them problems that they experienced with the services or products of the speaker's company, which the speaker had previously been unaware of.

With this success last year, we plan to expand the scale of such services, inviting more companies as well as other organizations or individuals from a wider range of activities, to make further studies regarding the possibilities and methods of channel time leasing services.

We find this type of bidirectional communication increasingly essential today when people are becoming more and more "individualized" and the needs for clothing, food, housing and recreation are growing more diversified. Industries who provide products and services for these needs must re-orient themselves to respond to such trends, and they often find that conventional mass media do not provide satisfactory answers. Some examples of such trends and consequences are

1) Audience rating of through-the-air TV programs is declining gradually.

2) The number of specialist magazines, as well as the degree of specialization, is increasing.

3) There is a growing public interest in new media.

2-5 Introduction of still picture data base

Microfilms have been the only source of still picture information for our system due to technical restrictions at the time our system was first installed. Now, we have ample access to still picture disks or video disks. There are several advantages that these more recent media can offer.

1) The original quality of picture is maintained.

2) Capacity is much greater (15000 to 25000 pictures per disk.)

3) Random access to contents.

Unlike VTRs or other media whose operating mode is almost always limited to "forward" only, the way information is provided and accessed will be greatly changed with more advanced disks, allowing users to get specific information, or have access to more general information, freely at any time, for their specific need.

It is likely that these media are most effective in providing educational programs or channel time leasing services as well, because the instructor or speaker will be able to select the most appropriate materials for his presentation according to the degree of understanding or interest of the subscribers.

3. HI-OVIS APPLICATION DEVELOPMENT

Our development has been limited to a large scale, housing development community (new town, or dormitory town). We are now studying the possibilities of installing similar systems in small to medium sized industrial development areas, for business application. Major emphasis will be placed on specific areas of interest, such as the following, in our future efforts.

1) To determine the position of Hi-OVIS in Office Information Systems.

2) The possibility of a link-up between Hi-OVIS and CAD/CAM systems.

3) Cost performance, or cost benefit.

4. CONCLUSION

There will soon be large scale, sophisticated CATV systems, data base systems and videotex services in Japan. At the same time, there will be progress in engineering techniques such as electronic cameras and in media such as video and compact audio discs. When these are realized, Japan will indeed enter the new media era. We are determined to make full use of the completely bidirectional function of Hi-OVIS and adopt new and more advanced technologies as much as possible, to promote further progress in cabled information systems in the new media era.

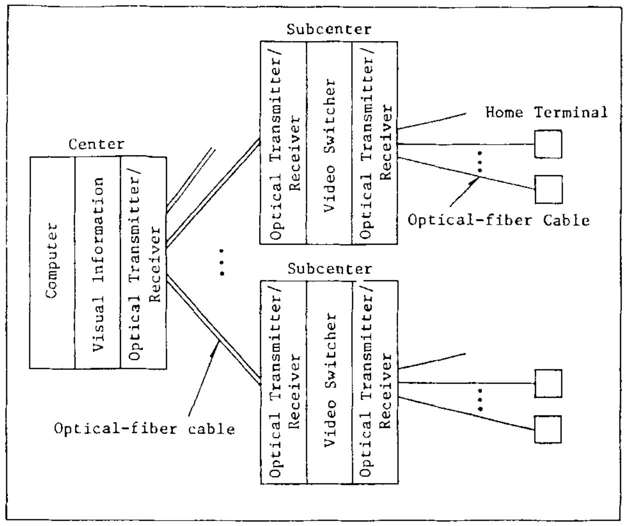


Fig. 1 Basic Configuration of Hi-OVIS

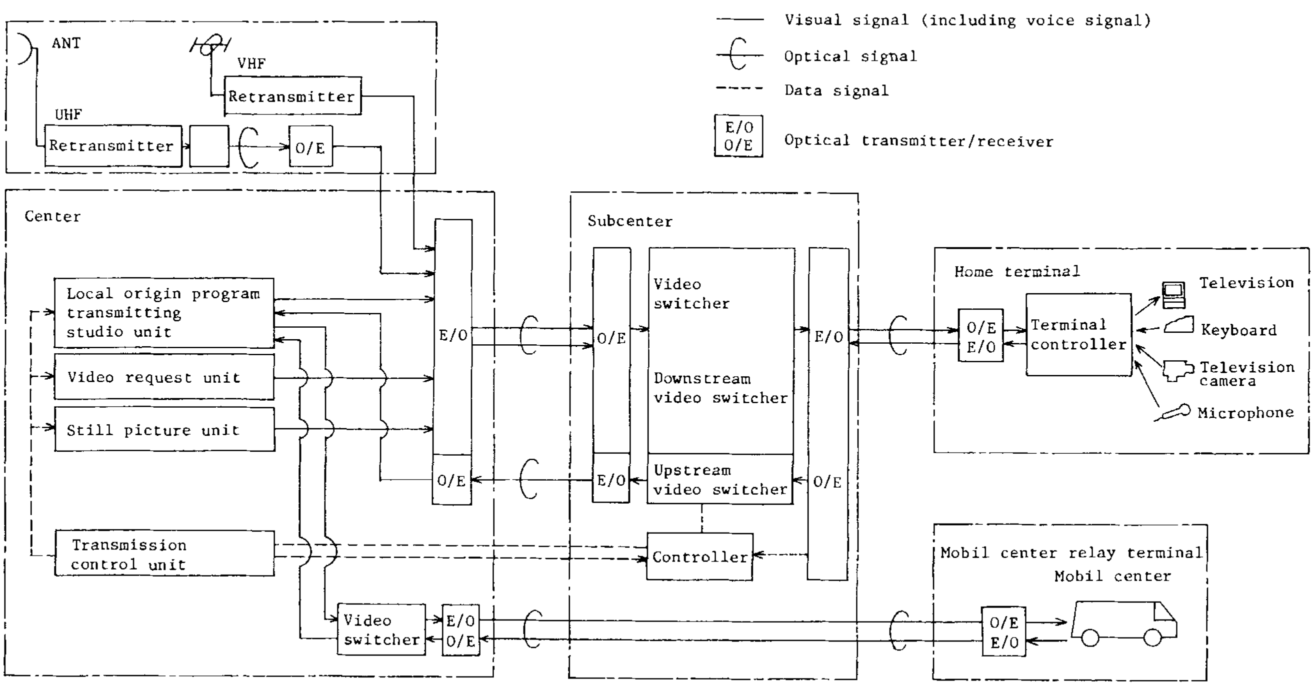


Fig. 2 Hi-OVIS Experiment System Structure

Table I. Outline of Hi-OVIS Services

Types of program		Hardware program	Software program (Max.)
Retransmission	In-area TV waves VHF	6	6
	UHF	1	1
	Out-of-area TV waves UHF	2	2
Studio-produced program		1	1
Video information programs	Video programs at fixed time	3	3
	Video programs by request	4	68
Steill-picture program	Character programs News	1	1
	Program Guide	1	1
	General Programs	4	50
	Microfiche programs	1	20
Subsidiary service	Program reservation	1	-
	Telop	4	-
Total		29	153

Table III. Major Sophisticated CATV Plans

By	Contents
I C N	Broadcast to start in 1985 in Machida, Tokyo with ultimately 30 channels for 50,000 families. They also have plans for a global station network using communications satellites.
Seibu Railway Co. Group	Their installations will connect all Prince Hotels in Tokyo, their vicinities and communities along their railway tracks, eventually 250,000 homes via 20 channels.
Tokyu Corporation Group	Their services will cover areas along their tracks connecting rural areas between southwest of Tokyo and northern part of Yokohama for 200,000 homes in future.
Marubeni Corporation, Uni Corporation, and The Chunichi Shimbun	A preparatory working committee by the three enterprises has been organized to implement their services in the Tokadai New Town in Komaki City, also in residential areas in Nagoya.
Marubeni Corporation, Hakuhodo Inc., and Tohoku Shinsha Film Co., Ltd.	They are establishing Japan's first software supply company in June for CATV applications. Full operation will begin about 1985 for 300,000 to 500,000 households initially.
Keio Teito Railway Electric Co. Group	Their plans are related to redevelopment projects in the vicinities of ten railway stations along their tracks extending to the west of Tokyo. CATV facilities will be installed in all stations along their Keio and Inokashira lines. They also plan to install optical fiber cable systems by 1984.

Table II

Comparison between Hi-OVIS and Mass Media

	Hi-OVIS Subscriber		Non-Subscriber		Hi-OVIS Subscriber		Non-Subscriber	
	Media useful for obtaining local information				Media that are reliable			
Total	1.Hi-OVIS	88.3	1.Newspapers	67.2	1.Newspapers	78.4	1.Newspapers	52.6
	2.Newspapers	84.6	2.TV	42.2	2.TV	75.3	2.TV	41.7
	3.TV	67.3	3.Radio	20.3	3.Hi-OVIS	42.6	3.Radio	18.8
Male Subscriber	1.Hi-OVIS	84.4	1.Newspapers	58.0	1.Newspapers	76.6	1.Newspapers	49.3
	2.Newspapers	81.3	2.TV	52.2	2.TV	75.0	2.TV	42.0
	3.TV	62.5	3.Radio	20.3	3.Books	39.1	3.Radio	18.8
Female Subscriber	1.Hi-OVIS	90.8	1.Newspapers	72.4	1.Newspapers	79.6	1.Newspapers	54.5
	2.Newspapers	86.7	2.TV	36.6	2.TV	75.5	2.TV	41.5
	3.TV	70.4	3.Radio	20.3	3.Hi-OVIS	48.0	3.Radio	18.8

	Media that are close to subscriber				Media that are useful to keeping up with events			
Total	1.TV Newspapers	75.9	1.TV	64.1	1.TV	84.6	1.Newspapers	66.1
	2.Hi-OVIS	62.3	2.Newspapers	54.7	2.Newspapers	82.7	2.TV	58.9
	3.Radio	22.8	3.Radio	28.6	3.Hi-OVIS	32.7	3.Magazines	28.1
Male Subscriber	1.TV Newspapers	78.1	1.Newspapers	58.0	1.Newspapers	89.1	1.Newspapers	69.6
	2.Hi-OVIS	48.4	2.TV	55.1	2.TV	85.9	2.TV	52.2
	3.Books	25.0	3.Radio	18.8	3.Magazines	31.3	3.Magazines	26.1
Female Subscriber	1.TV Newspapers	74.5	1.TV	69.1	1.TV	83.7	1.Newspapers	64.2
	2.Hi-OVIS	71.4	2.Newspapers	52.8	2.Newspapers	78.6	2.TV	62.6
	3.Radio	24.5	3.Radio	34.1	3.Hi-OVIS	42.9	3.Magazines	29.3

INCREASED PERFORMANCE AND REPEATABILITY FOR PORTABLE CATV MEASUREMENT SYSTEMS

Syd Fluck

WAVETEK INDIANA INC.

ABSTRACT

Microprocessors and large scale integrated circuits as major elements in test instruments provide significant benefits. The speed and packaging density allows the designer to set up, control and display the results for a variety of measurement requirements.

While most of these measurements for CATV are analog functions, converters (A to D and D to A) allow easy access to the power of digital processing.

Digital support circuits which utilize large scale integration are used by the computer industry in very large quantities, consequently the designer finds the cost performance ratio to be excellent.

Designing portable measurement systems utilizing these advantages may provide a combination of functions which would normally require several instruments and a skilled operator. An user friendly integrated instrument will allow good repeatability results, even with a less experienced operator.

INTRODUCTION

At the 1979 NCTA Convention Marv Milholland and myself, introduced the concept of microprocessor control for CATV instruments. This period marked the departure from general purpose and arrival of application engineered measurement systems for CATV. The technical growth of our industry created a challenge to both the system operator (find enough skilled people) and the instrument designer (keep up with trends without gambling large capital investments too early). It became clear that the availability of skilled people would lag demand, operators would need to make more efficient use of their key people.

It was suggested that an instrument designer must focus on the goal to provide test equipment which will allow the operator to gain the most useful information about the condition of the system under test, in the time spent making tests and measurements.

We are looking at return on investment and with a limited human resource, the performance of the equipment could justify its cost. Human engineering and built-in intelligence would enhance the efficiency of the "man and his machine" while in some cases allowing complicated measurements to be performed with a less skilled operator.

PERFORMANCE

As defined by Webster, performance is the execution of the functions required of one.

An instrument has many dimensions to its performance, the most important of which is the ability to make the desired measurement, the environmental insensitivities, the package compatibility.

The instrument must be cost effective which is how the price performance ratio is evaluated.

A good rule is avoid "the ultimate machine", put in what is required, consider the human interface and provide an instrument that will give the user the most for his money.

THE MEASUREMENTS

In order to achieve an optimum price performance ratio it is necessary to analyze the requirements for a series of related tests and establish an algorithm. An example might be measurement of crossmodulation in an amplifier. This measurement could be done by analyzing the sideband components on a CW carrier, which are the result of intermodulation distortion. If this measurement were made with a conventional Spectrum Analyzer one would select span, center frequency, resolution bandwidth, scan rate, and video filter bandwidth.

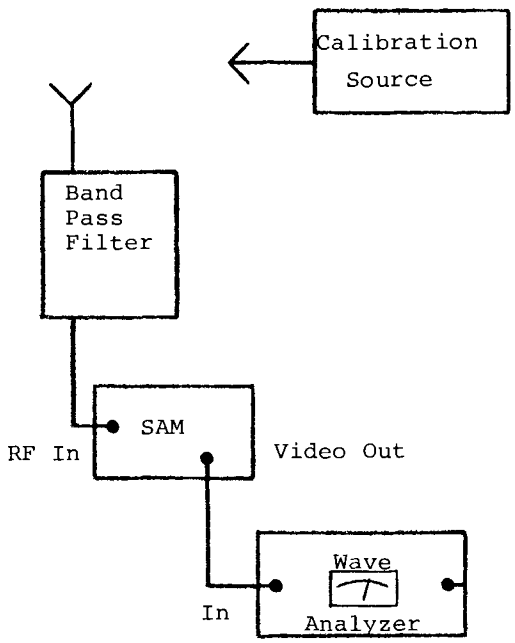
On a general purpose instrument some of these selections are uniquely related by ganged controls but because of the flexibility, a skilled operator is required to achieve optimum performance.

An alternate method is the combination of a signal level meter and a wave analyzer.

This method shown in Fig. 1 is more

cost effective but has the disadvantage of requiring interconnection of instruments and a calibration procedure to insure that the combination is being properly utilized.

Fig. 1



Wave Analyzer method to measure crossmodulation to point under test.

Performance of this measurement in a microprocessor controlled System Analyzer can be reduced to a hardware/software algorithm. Processing the RF input like a signal level meter the video detector output is internally presented to a calibrated tuned amplifier, who's output is detected and processed by an analog to digital converter. The digital output is compared to a precalibrated table or program in memory to establish the readout for the CRT display. The indication will be an alphanumeric presentation o the equivalent crossmodulation in dB down from the carrier. This method will minimize the operator interface and eliminate much of the setup decisions. This should allow a less skilled operator to achieve repeatable, accurate results.

UNIQUE SYSTEM FUNCTIONS

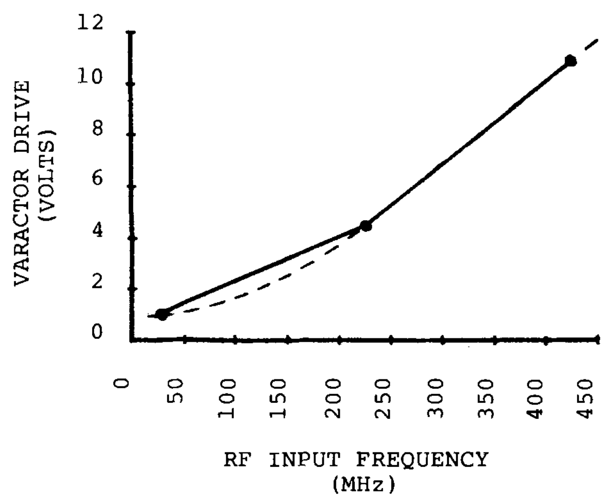
The previous cross-modulation measurement was one of many algorithms implemented in a new System Analyzer designed to provide the objective advocated by the writer. If we examine some of these algorithms, which comprise thousands of bytes of code; we will gain some insight into the power of the modern components and design techniques. There are many similarities between the System Analyzer and a conventional Spectrum Analyzer.

The most obvious is the requirement to set span, scan rate and center frequency. A digital to analog converter (DAC) is set up to have ≈ 27 KHz/bit resolution.

Entering a center frequency via the keyboard activates a binary search which compares the first Lo frequency (VCO) to a calculated value (CF=VCO-1st IF) and connects the DAC output as required. The selected span can then be established by selecting the optimum slope for that span at the selected center frequency. Since the center frequency is controlled it is possible to optimize the slope for the span on both sides of the center thus eliminating the need for noisy and temperature dependent sweep linearity controls. In Fig. 2 the setup from memory is shown superimposed over the curve for the typical varactor drive voltage to the first Lo for a given input frequency.

The table values for the different center frequencies and spans for 2A, 2B, and 2C show how independent selection of slope for left and right of center frequency can significantly improve the span accuracy. Linearity improves as span is reduced, however, with a marker system which actually counts the first Lo frequency to establish its value the need for absolute linearity is not a primary requirement.

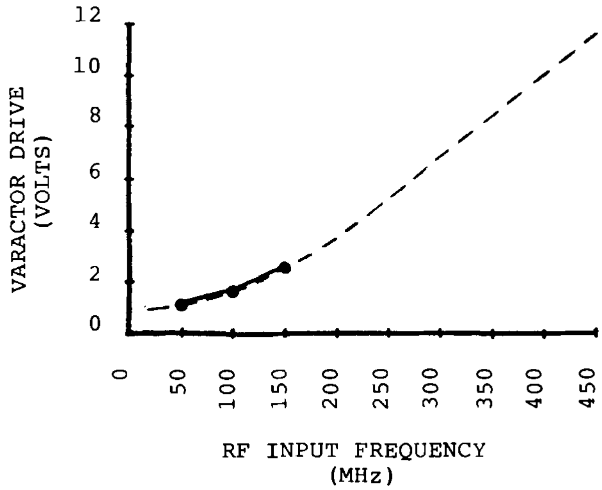
Fig. 2A



From A Table in Memory

C.F. (MHz)	Span (MHz)	Slope volts/MHz Left	Right
225	400	.021	.029

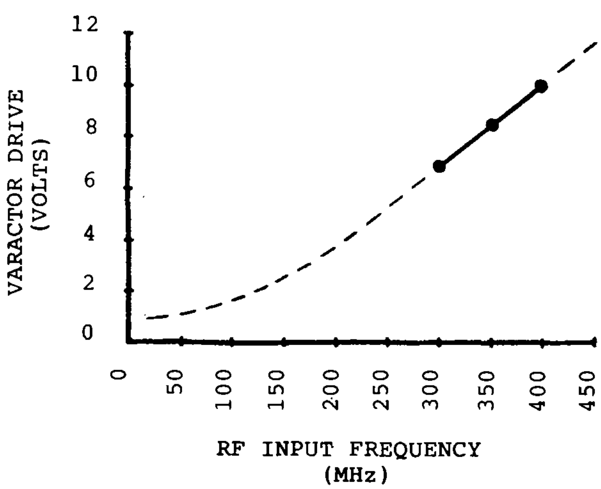
Fig. 2B



From A Table in Memory

C.F. (MHz)	Span (MHz)	Slope volts/MHz Left	Right
100	100	.015	.019

Fig. 2C



From A Table in Memory

C.F. (MHz)	Span (MHz)	Slope volts/MHz Left	Right
350	100	.029	.029

SYSTEM ANALYZER BACKGROUND SWEEP

Using the entered center frequency and span to determine the Δ DAC increment value, a binary search method is used to find out the DAC value of entered center frequency. The DAC value for center frequency is multiplied by 2^8 to make it as a 24 bit value. There are 125 points between left hand side CRT and center of CRT so the DAC value of starting frequency = DAC value of center frequency - 125* Δ DAC increment. All three values are 24 bits in length. We use the following formula to paint the screen.
DAC value of Nth point =
(DAC) value of starting frequency + N* Δ DAC increment) ÷ 2^8.

N can be any number from Ø to 124. Dividing by 2^8 is necessary because we only have a 14 bit DAC in our frequency control system.

AMPLITUDE MEASUREMENT

The traditional Spectrum Analyzer must be set up with care when correlating carrier and carrier to beat ratios with signal level meter readings. The reason is that the signal level meter uses a peak detector. The peak detector allows the signal level meter to be calibrated at the RMS of the carrier during peak sync.

There are many settings for a conventional Spectrum Analyzer which will mask this peak response.

The System Analyzer displays amplitude of carriers using the peak detection concept described for signal level meters.

The concept becomes unique when we consider the system is to measure a series of levels as it scans the frequencies determined by the span settings.

The measurement becomes further complicated by the fact that due to cost and power considerations the system will only display 250 frequency cells with ± .25 dB amplitude resolution. When spans are large the microprocessor divides the total number of available increments by 250 and steps through that number of increments (N) with the peak detector activated. At the end of N increments the peak detector will contain the largest amplitude of the previous N increments. The value in the peak detector at this time is converted by a high resolution (12 bit) analog to digital converter and stored into memory as one of the 250 display frequency cells. The microprocessor then clears the peak detector, increments the pointer and repeats the previous process for the next frequency cell. In the 10 dB/division mode the 256 point vertical display (8 bit) represents ± .25 dB of resolution of the displayed data.
Note: It is interesting that with a 60 dB dynamic range the human operator can just perceive this magnitude of variance even on an analog scale with infinite resolution.

Since the number converted by the analog to digital converter has 4096 point resolution (12 bit) the use of a special marker system will allow the alphanumeric presentation of the amplitude value at a frequency cell to a higher degree of accuracy than the graphical display.

Scan loss is under control of the microprocessor, if the span is large the scan time is at a maximum (.7 sec) if the span is small the scan time is reduced proportionally.

This adaptive scan rate concept is applied when the measurement algorithm calls for narrow IF filter resolution bandwidth or heavy video filtering. Additional factors which effect the amplitude measurement accuracy are; the attenuation versus frequency (slope) due to cables, attenuators, input filters and converters. Also the incremental linearity of the log amplifier and the temperature variation of the entire measurement system.

To address the first area (slope), the microprocessor was programmed to modify the detected level value at any frequency to compensate for the slope at that frequency. The consideration for linearity and temperature variation are somewhat independent but the implementation of an internal calibration source, which is exceptionally temperature stable, can be activated at any vertical position to establish a desired reference. The entire vertical scale is modified to make that position calibrated.

With the feature of alphanumeric readout, the marker system becomes a valuable performance contributor. The microprocessor allows the operator to manually position the marker to any area of the screen and the readout will display amplitude and frequency for that point. Two such markers can be activated and will be used more extensively for some of the unique measurements.

The marker can be sent to the peak in an area via keyboard entry and in a similar manner that marker and carrier can be moved to the center of the display.

A zoom function takes the present span and reduces it by a maximum of 5 and a minimum of 3 to expand the resolution in the area of interest.

A useful performance enhancement is the programming of narrow span around the various channels. There is a table in memory with these center frequencies along with a program to activate the 10 MHz span around the table value when the operator selects a particular channel. A split screen mode can be activated to look at two channels at once or look at one channel on the left and a large area of the spectrum on the right of center.

ADDITIONAL MEASUREMENTS

Frequency deviation below 200 KHz peak to peak can be measured by placing the marker to the peak of the carrier to be tested.

The selection of Δ F from the keyboard sets up an algorithm where the instrument goes into a zero span mode around the marker frequency, an AFC circuit is activated in the final IF and a calibrated discriminator output is compared against a table in memory.

The results are peak averaged and displayed with updating of graphic data every sample and updating of alphanumerical display with the largest of every 5 samples.

Composite beats and carrier to noise measurements are made with similar algorithms.

It is necessary to turn the carrier off at the head end to make the composite beat measurement. Only a single marker is required.

The marker is positioned to the peak of the reference carrier and amplitude measurement is performed by the instrument. Pressing a 2nd/3rd order key activates the composite beat measurement. The instrument changes resolution bandwidth to 30 KHz, selects an averaged output with a 10 Hz video bandwidth and reduces the scan rate to account for the slower response for this measurement.

Since the noise floor for this condition is significantly lower an offset in display and readout is effected thus extending the beat measurement range to greater than 70 dB. The difference between the measured amplitude before and after selection of this function is displayed and the marker remains active to give the operator a means to position it on the exact peak of the composite beat

Carrier to noise is measured by taking the difference between two markers, one of which is placed on the peak of the carrier while the other is placed on the noise floor. A correction factor is applied to the readout, compensating for the difference in bandwidth and the relationship between peak and RMS noise.

Hum modulation is measured by activating a calibrated low pass video amplifier/filter and comparing the detector output to a reference table in memory. Again the display of results is effected in a like manner to measurements previously reviewed. Some of the additional measurements which enhance the performance of such an instrument are temperature measurement, internal automatic calibration, peak hold, A B memories for comparison of measurements, built-in diagnostics, and flexibility for future expansion.

A simple matrix key pad which is utilized as an extension of the instruments memory allows a human interface which can effect complex measurements with one or two key strokes. The results of stacking these functions and their straight forward access, assures maximum performance and repeatablity of results.

JAMMING TECHNIQUES FOR OFF-PREMISES ADDRESSABILITY

by

Robert V.C. Dickinson

E-COM Corporation
A Subsidiary of AM Cable TV Industries, Inc.
Stirling, NJ

A great deal of attention is being given to off-premises control of premium cable services. Off-premises devices have usually taken the form of either "pole-mounted converters" or hybrid systems involving fiber optics. This paper presents a description of an off-premises premium entertainment control technique employing jamming signals to render unauthorized channels unintelligible. This approach offers some major features and provides many operational and economic advantages. A description of this product and its operational effectiveness will be presented in this paper.

RATIONALE FOR EMPLOYMENT OF OFF-PREMISES JAMMING TECHNIQUES

Since major revenues in CATV systems are produced by premium services, it is no wonder that an enormous amount of effort has been devoted to protection of these services from unauthorized viewing. Many manufacturers offer scrambler/descrambler systems for this purpose.

It is very difficult, however, to build a high security scrambling system which must both work in a broadcast mode and employ a relatively inexpensive decoder. As a result the security of most scrambler/descrambler systems is not high, and the business of selling "simple fixes" to defeat these scrambling systems and provide the means to illegally view premium services continues to grow.

As the number of premium services has increased, addressability of converters and the ability to control multiple individual services have become very important. These requirements have increased the complexity of the converter/descrambler and, in turn, have produced other areas of vulnerability that have also been exploited by the "Pay TV Underground". There is an ever-growing list of "fixes" ranging from a $5.00 set of parts that will allow reception of suppressed sync scrambling, to all types of schemes to remove or falsify data carriers, in some way defeat the addressability, or modify it to provide the desired end. Stolen converters are often altered (if necessary) and sold as "lifetime subscriptions" to one or more premium services.

Unfortunately, the equipment that controls the decoding of both the addressing and the scrambled signals is continually in front of the user in the privacy of his residence, thereby inviting experimentation and tampering or at least inspiring him to purchase a "bootleg box".

One approach designed to alleviate this problem is the "pole-mounted converter" where the entire converter is removed from the premises and only a low cost control device is required within the residence. The "mini-hub" approach using fiber optics uses somewhat different technology, although its operational features are much the same as those of the pole-mounted converter. Both approaches all but eliminate direct tampering with critical hardware since it is no longer in the residence.

The pole-mounted converter, however, has some practical shortcomings. A major one is the fact that (in the basic implementation) only one channel is transmitted down the drop cable to the TV receiver. As a result, a separate outside converter is necessary for each TV set in the dwelling and additional drops are necessary for additional sets. The pole-mounted converter requires that the television receiver be tuned to the single output channel of the converter, thereby excluding the expensive channelization and remote control features of the often-encountered "cable-compatible TV".

In an effort to cope with these problems and gain other advantages, jamming techniques have been developed. The basic concept of jamming is to render unauthorized channels unviewable by the use of interfering signals. The jamming device is mounted on the strand in order to reduce tampering. The specific jamming required for each drop is under the positive control of a one-or two-way data system thereby achieving "addressability". When off-premises jamming is used, all signals come down the drop as with a standard CATV system configuration, except that those signals that are not authorized are unviewable. Commands are given to remove the jamming only from those programs that are authorized for the specific drop. Once in the home, since it is academic which set or how many sets receive the authorized programming, the drop may be split as required using standard CATV practice.

Plain, non-addressable converters of any type can be employed as well as direct (no converter) input to cable-ready TV sets. Since any standard converter may be used, converter changes or substitutions become routine. Since ownership of standard converters is not a threat to other cable systems the sale of converters to subscribers is quite practical and can greatly decrease operator capital and cash needs. Program authorizations can be changed very quickly via the data system allowing phone-in ordering of special events. Where two-way transmission is employed, an ordering device (keypad) can be provided for impulse-pay-per-view, opinion polling and the like. Other economic advantages which stem from the specific configurations of the jammer will be discussed later in this paper.

Security of the pay TV product in such a system is greatly enhanced due first to the virtual impregnability of the strand-mounted unit, and second to the irreversible destruction of visual and aural information by the jamming signals. In addition, when the jamming is removed, there is no degradation of the television image, as there may be in scrambler/descrambler systems, since a clean signal without additional processing is presented to the viewer.

TECHNICAL CONFIGURATION OF THE JAMMING MODULE

The E-COM Tier-Guard System implements premium TV control with jamming techniques. The jamming module was originally designed as part of the E-COM TRU-NET 500 Multiservice Communications System. The TRU-NET 500 is a comprehensive, high capacity, low cost communication system which offers interface units to implement a wide range of residential services such as security, energy management, meter reading, premium service control, home computer interconnect, and videotex. Any service addressed by the TRU-NET 500 can be installed individually or in concert with one or more other services. Control of premium TV is provided by what is known as the Tier-Guard Tap (TGT) which is but one element in the TRU-NET 500 system. TGTs are employed in place of normal subscriber taps. A network of TGTs is controlled by the System Communication Controller (SCC) usually located at the cable system headend. A 38 kilobit/second data stream is used to communicate with the TGTs on either a one-way or two-way basis (two-way hardware is supplied allowing subsequent hands-off upgrading when desired).

The jamming signals are provided by an internal frequency-agile system allowing up to 16 tiers of service. In the initial product, each tier may be selected under system control to consist of either one channel or three contiguous channels and may be assigned at will over the highest octave of frequencies available in the cable system, i.e., 120 to 240 MHz, 150 to 300 MHz, 225 to 450 MHz, etc. Channel assignments may be IRC or HRC systems. The TGT also includes a remote disconnect feature for each drop that, when initiated, blocks all television service but allows on-going communication with security, meter reading and other interfaces when installed within the residence.

Since suppression of the aural information is often deemed as important as control of the visual, the jamming signals are injected in a way that drastically effects both elements of the TV signal. The traditional method of inserting interfering carriers has been to inject the carrier midway between the aural and visual carriers and provide a positive trap to remove the interfering signal. In the TGT jamming system, such traps are unnecessary since the jamming is completely controlled at the tap via the data channel. In order to make it virtually impossible to effectively remove the jamming signal the interfering signals are injected in close proximity to the TV carrier frequencies. Any attempt to trap the interfering signals will destroy the desired TV information in the process.

Considering reliability, loss of the jamming signal will allow receipt of unauthorized premium product (an event we doubt the average customer would report as a service call). For this reason certain critical parameters of the jamming system are continually monitored by the system. Failure to sense proper operation of the circuitry as indicated by these "flags" will cause a fault signal which completely shuts-off the unit in a one-way system. The shut off of the unit will obviously precipitate a service call. In a two-way system this information is returned to the headend where it initiates a service call and allows discretionary action.

The system described above is extremely secure. The one obvious way to defeat it is the application of a "pressure tap" on the distribution cable where the signal is clean. This "fix" is visually auditable and provides prima facie evidence of the attempted theft of service.

The TGTs are installed in place of the normal subscriber taps. Units are available with 4, 6, and 8 outputs. Economies achieved by the use of a higher number of output ports are quite substantial and often warrant the installation of longer drop cables to take advantage of this feature.

The TGT modules have another important characteristic. Regardless of the tap value the through loss is minimal (0.5 dB). As a matter of fact, discrete tap values are not supplied since this parameter is field adjustable. The installer or serviceman need only stock a single part for replacement of, say, all 4-way taps and set the specific tap value required at time of installation.

Due to the reduced through loss of the TGT, spans between amplifiers can be longer. Studies have shown that a 15 percent reduction in line equipment costs is possible where TGTs are included in the original design. In rebuilds, it is often possible to replace normal taps with TGTs and thereby increase the high frequency response of the system and therefore the number of cable channels carried without costly physical respacing of the amplifiers or replacement of the cable.

JAMMING EFFECTIVENESS

The effect of the jamming varies with each type of TV receiver. In general, it is possible to jam vertical sync, horizontal sync, and AGC action of TV receivers. In addition, the injection of a pulsed interfering carrier, as employed by the TGT system, tends to "chop up" the picture to the point of unviewability. The TGT jamming algorithms have been optimized to achieve multimode jamming on all types of TVs. It can be appreciated that the synchronizing functions in newer TVs with countdown sync circuits are more difficult to disrupt. However, all TVs are to some degree susceptible to sync jamming. Various TVs have grossly different responses to pulsed interference in the AGC circuits. In some sets, total obliteration of the picture is achieved by blocking only the AGC, while in others the effect is only partial. All sets, of course, are susceptible to chopping up of the picture. As a result, at least two jamming modes are effective on all old and current production TV receivers.

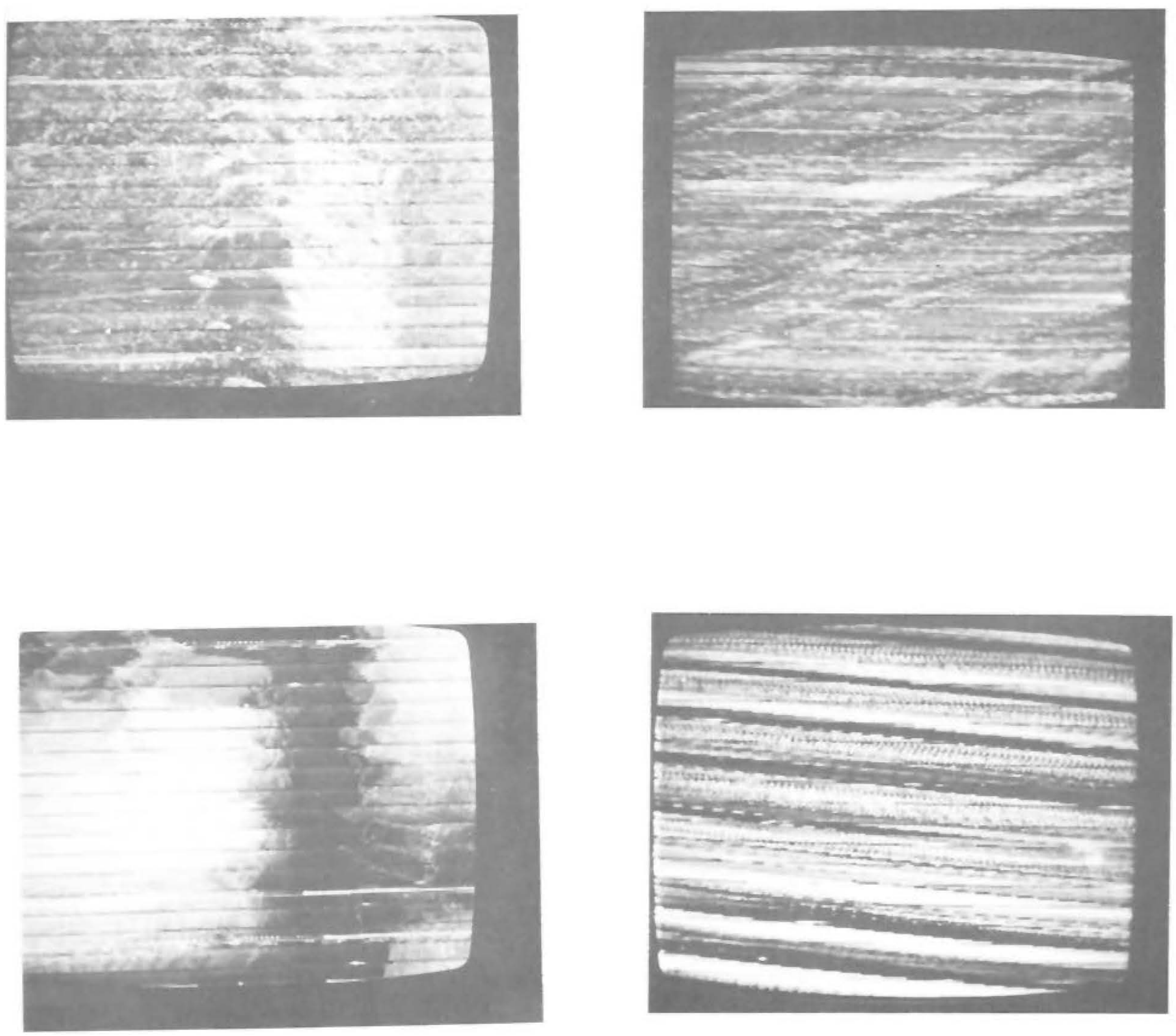
Obviously, the bottom line in evaluating a product like this is the performance (effectiveness of jamming). Some advocate only partial jamming of program material in order to make enough of the picture viewable to act as a teaser. For other programming, extra effectiveness is required for both audio and video information. The TGT system offers variable jamming options which are all under the control of the system operator. The jamming algorithms of the TGT are altered by changing the number of jamming impulses per second. Channels requiring higher levels of protection can be given greater disruption by increasing this pulse rate.

The illustrations accompanying this paper attempt to show by still photographs (which hardly portray the dynamics of the process) the effects of jamming upon the visual information as experienced by various television receivers. The aural information is obscured by various pulses and modulations that produce extremely loud and annoying sounds to mask the aural content.

SUMMARY

The off-premises jamming approach to pay TV security is an extremely attractive one. It eliminates the problems of multiple sets and cable-ready receivers. It is very effective and virtually tamperproof and provides tiering and intensity options under the cable operator's immediate control. This technique provides an economical means of pay TV product protection plus yields substantial advantages in cost and maintenance savings when included in new cable systems and rebuild applications.

TYPICAL RESULTS OF TIER-GUARD JAMMING SHOWN ON FOUR TV RECEIVER TYPES



MILTON KEYNES AND BEYOND, THE NEXT GENERATION SYSTEMS

E John Powter

British Telecom Research Laboratories

ABSTRACT

The all optical fibre switched-star trial system at Milton Keynes will be reviewed. Differences between the British and American markets for cable-TV are considered before describing the services and requirements for the next generation system. This system uses both optical fibre and co-axial cables, with elements of tree and branch and switched star topologies, to provide a network which is well matched to the services to be provided. An outline of the system is given, and reference is made to available UK government reports on cable TV.

INTRODUCTION

For more than a year British Telecom has had in operation an all optical fibre switched star cable network at Milton Keynes, a new town in the centre of England. Although this scheme is on a very small scale, serving only 18 homes, it provided very valuable experience for the design of much larger systems. Much of this design work has already been completed, and major contracts have been placed for the supply of equipment. The first large scale scheme will be ready for service in the last quarter of 1984, if regulatory conditions permit.

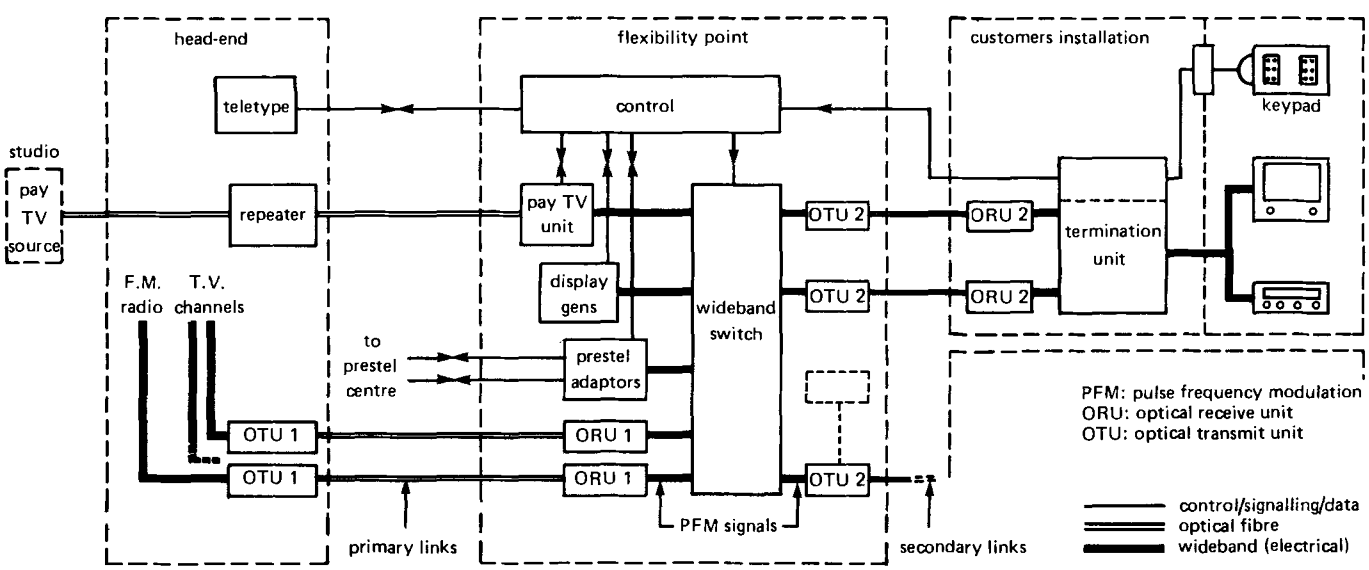


Figure 1: The Milton Keynes System

THE MILTON KEYNES TRIAL

The Milton Keynes scheme has been well documented elsewhere (Ref 1) but to set the scene and provide background to the description of the next system it is as well to review it briefly. The network topology is shown in Fig 1. The primary link carries the channels (one per fibre) from the head-end to the switch. This link uses graded index fibre, 850 nm edge emitting LED's, pulse frequency modulation, and is over 3 km long. At the switch point each incoming fibre terminates on an optical receiver unit employing an avalanche photodiode. The PFM output from the receiver forms an input to the wide-band switch which, under microprocessor control, can route any input to any output. The PFM outputs from the switch feed optical transmitter units, again using 850 nm ELED sources. The microprocessor scans the secondary link signalling information for channel requests from customers, and additionally performs link monitoring functions. From the switch point a two fibre cable goes to each customer. This cable has two copper coated steel strength members which are used to carry signalling information from the customer. The customer's installation consists of an optical receiver unit using PIN diode detectors prior to an FM demodulator. The resultant baseband TV signals are then up-converted to UHF to feed via coax cable to the aerial input of a standard UK television receiver. The customer chooses his required programme by means of a push button remote control channel selector, and has two simultaneous channels available, making it possible to view one channel whilst recording another. Each customer also has access to Prestel, British Telecom's videotex service with more than 200,000 pages of information. This is achieved by putting text generators at the switch point, and using the video outputs from these as inputs to the video switch. In this way, and in conjunction with the signalling path from the switch to the customer, access is given to a videotex service with no additional equipment in the subscriber's home. Videotex generators are shared between customers at the switch point leading to economy in equipment provision. The main features of the Milton Keynes scheme are thus:

- Optical fibre transmission offering excellent signal quality over long distances without the need for repeaters. Not susceptible to ingress or exgress of interference, a point vividly demonstrated on the occasion of a severe thunderstorm at Milton Keynes which severely damaged over one hundred amplifiers on the conventional co-axial system, yet the video transmission over the optical fibre system was unaffected.

- Switched-star topology offering protection against programme theft, no scrambling leading to better signal quality, easy implementation of interactive services.

THE BRITISH MARKET

Before going on to describe the development of the Milton Keynes trial into a much larger cost-effective scheme, it is as well to consider the market situation in the UK. There are a number of factors which make a direct translation of the American experience to Britain uncertain (Ref 2).

- Transmission and production qualities are high and reception is near universal. Broadcast TV offers a wide choice, with 4 TV and two "breakfast-time" channels.

- Viewing figures for the new 4th channel and one of the "breakfast-time" channels have been poor. The take up of the experimental subscription TV service on some existing cable schemes has been disappointing. Overall viewing figures have recently dropped.

- Market studies indicate a substantial discrepancy between the cost of installing and running a cable-TV network (due to high environmental standards it is most unlikely that US installation practices will be allowed in the UK) and the monthly charges that a customer is prepared to pay.

  There are however some peculiarly British factors which may have an influence on the take-up of a cable-TV service in the UK.

- 33% of new TV sets purchased are equipped to receive and decode broadcast teletext services.

- The penetration of video tape recorders is at 12% the highest in the world, and is predicted to rise to 33%.

- Home computer penetration is 5%, expected to rise to 10% next year.

From this evidence many conclusions can be drawn, one is that a cable system offering "more of the same" may not be totally successful, although undoubtedly there is a market for good feature films.

The high penetration of video tape recorders may be explained by the viewer wanting control over his time of viewing a particular item, either because he is otherwise occupied when it is shown, or because there is simultaneous showing of items which interest him on different channels. In an effort to maintain their audience ratings, competing broadcast companies show popular programmes at the same time. The advent of the remote controlled teletext set has caused some concern amongst those advertising on the independent channels that during commercial breaks the viewer may switch to the teletext service. Many home computers are used for playing video games.

To be successful a cable system must offer the consumer more than is already available, or similar services packaged in a more convenient way at a lower perceived cost. Desirably it should offer the facilities of a home entertainment centre without the capital cost of extra equipment, and for the cable operator should possess the potential to evolve towards an integrated wideband communications network with capacity for new services when demand arises:

Thus mix of services could be:

- Distribution TV - Basic, subscription, pay-per-view.
- Videotex - Alphanumeric and photographic.
- Home data services
- Individual video - eg video telephone, video library.
- Business services - Data and video.

THE NEXT GENERATION

Unfortunately this mix of services requires a mix of cable topologies. Broadcast type services are best distributed by a tree and branch network, and a limited amount of interactive capability can be provided to cater for pay-per-view services and low speed telemetry type data. However, despite a considerable amount of ingenuity displayed by system designers, the tree and branch network is fundamently limited in the amount of traffic it can handle. Services that demand individual subscriber access are best handled by a star type network, the star implemented either electrically or physically.

Mixed services are best handled by a mixed network topology, and that chosen for BT's next integrated services wideband network is shown in Figure 2. It is basically a switched-star network, but has elements of a tree network to give economies in the provision of broadcast channels.

Broadcast services are fed to each wideband switch over optical fibre cables and passive optical taps. The distances from hub site to switch may be up to 50 km, and fibre was chosen in this part of the network, the primary links, because of its superior transmission performance. Equipment is being developed which will allow transmission of 4 TV channels over one fibre using FM, narrow stripe laser source at 850 nm. The graded index fibre is required to have a loss of 3.5 dB/km, with a bandwidth of 600 MHz km. Initially each switch point will be provided with 5 tapped fibres, giving a 20 channel capacity, and an additional 5 dedicated fibres, two of which are used for a signalling and control path to the hubsite (2 Mbit/second) and three giving an additional 12 channel capacity for individual services.

Switching is done at baseband, the development of a hybrid circuit has reduced the size of the switch such that it can now be housed in a roadside cabinet. Each switch serves up to 300 subscribers, who are connected by a small bore co-axial cable in a star configuration. By keeping the upper frequency on this secondary link to below 100 MHz, a reach of 500 metres can be obtained. Initially, each subscriber has access to two independently switched TV channels, FM radio, and a bothway signalling channel. Provision has been made in the frequency plan for an additional TV channel, an upstream video channel, and a bothway high speed data circuit. Furthermore, account has been taken of a possible extension to the bandwidth required for broadcast TV channels with the advent of DBS signals. As in the Milton Keynes trial, channel selection is controlled by a processor at the switch point, which receives channel requests from the subscriber, and accesses eligibility information from the central management system. Videotex generators are also placed in the switch, their outputs, at video, being transmitted to the subscriber in the same way as standard TV channels, whilst their inputs are fed, via the signalling and control data link, from the videotex subsystem at the administration centre. The videotex subsystem is an integral part of the cable network, offering not only access to interactive information pages eg advertisements, mailbox, shopping and banking, ability to change censorship passwords, general help. Furthermore a games package is incorporated, offering in addition to customer-computer games, customer-customer games and educational facilities. Gateways are provided in this subsystem to other data bases, such as BT's national Prestel service or private viewdata schemes. Customers can be provided with the facility not only to access information from the database, but also to input formation, eg advertisements. To achieve this, the customer signalling system is capable of supporting a full alpha-numeric keyboard, although this will be available only at extra cost. Another gateway is to be photographic videotext system. Here photographic images are stored in a computer file and can be recalled and displayed on the subscribers TV set. In this case transmission is at video from the head end to the subscriber, and uses the channels provided by the dedicated fibres to the switch points. This service will be of interest to those waiting to sell high capital cost goods, eg houses.

The video library subsystem also uses these dedicated channels. Here, customers can access any item held, on video disc, at a centralised library location. Because the customer-disc interaction is one to one, the customer can be allowed to control the disc player, and facilities such as fast forward and reverse, still frame, and search to a frame are available. Each disc can store up to 50,000 frames of information, each one can be accessed individually, opening up exciting possibilities in the area of programmed learning video encyclopaedia, as well as the more normal play through items. This will be a premium service for which the customer will be charged an amount similar to that of renting a prerecorded video tape, it is therefore expected to be a service that the average customer will use only occasionally. The system design is, however, modular, such that it can be enhanced to meet demand.

The management subsystem keeps a record of customer eligibility for particular services, as well as records of parental lock and other passwords. This information is downloaded to the processors in each switch point when necessary. It also provides data for customer bills, and maintains an overview of the network operation. Interfaces can be provided to programme providers, and statistics on systems use obtained. Associated with it, although able to operate in a stand-alone mode, is a system planning aid which holds geographic information concerned with the location of cables and equipment and has information on transmission planning rules and costs available to it. This enables the system, or extensions, to be planned and costed quickly and easily.

The customers installation consists of three items. A customer's termination unit, which receives the VHF signals from the system and up-converts to UHF to feed a conventional TV set and contains a simple microprocessor to perform signalling and monitoring functions. This box needs to be mains powered from the customer's supply, but can be located

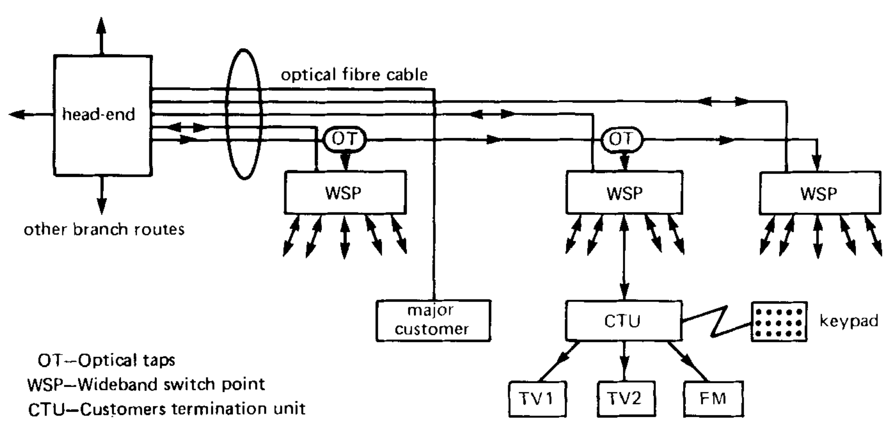


Figure 2: Network Topology

anywhere in the house. It is connected to the TV sets and FM radio by conventional in-house UHF wiring. Communication with the system is achieved by a hand-held infra-red remote control keypad (either full alpha-numeric or simplified service select and library control only), the receiver for which is a very small box mounted on the TV set. Signalling information is passed from this small box to the customer's termination unit over the UHF co-axial cable.

PRESENT POSITION

The most advanced system offering all facilities is doomed to failure if it is prohibitively expensive to install and operate. The mature costs for the switched star system described here; that is the basic system offering broadcast, subscription and pay-per-view TV, access to the videotex and photographic videotex subsystems with all the interactive facilities, is some 20% higher than a conventional one-way addressable co-axial system constructed and installed to UK standards. This higher cost must be considered in the light of the potential revenue earning capacity and operating costs of the two systems. The switched star system, with its sophisticated monitoring and control system, as well as its almost total immunity from programme theft could well show significant savings in maintenance and operating costs over its tree and branch competitor. Add to this the UK governments intention to offer longer franchises to the switched system, and the case for its installation from the outset is very strong. As to the availability of the equipment, all the hardware designs have reached prototype and most are in the production phase. Software definition and preparation for the control system is in-hand for a system that will support 100,000 customers, greater numbers being served by modular addition. Technically the first customers could be receiving service by the last quarter of 1984, but the timescales are likely to be dictated more by commercial and legislative considerations, rather than by system availability.

REGULATION

Britain is in the process of establishing the regulatory framework for new cable-TV systems. The Information Technology Advisory Panels' report (ITAP), published in early 1982, advocated the liberalisation of cable systems. Additionally the Government accepted that direct broadcasting by satellite (DBS) could be introduced. The Hunt committee, established in the wake of ITAP to consider the impact of cable on broadcasting, reported towards the end of 1982, and a Department of Industry committee, chaired by Dr Eden, has been considering technical standards and is due to produce its final report in summer 1983. A Government White Paper is expected by the end of April 1983, setting out policy and franchising arrangements.

EVOLUTION

It must be admiited that the cheapest way of distributing TV signals to subscribers is by a tree and branch co-axial cable network, and indeed British Telecom is actively pursuing this approach as well as the switched-star system described in this paper. However, the provision of switched star topology enables the system to evolve as demand grows, as well as easing some of the problems (picture degradation due to scrambling, programmed theft, limited interactive capability) encounted with tree and branch networks. Indeed, the strength of the star systems is that sufficient transmission capacity is installed on the final link to the subscriber, which is generally the most expensive part of any cable network, to cater for existing and future demands for entertainment and telecommunication services. By upgrading equipment at either end of the link, and with no additional civil engineering work, the system can evolve to an integrated services wideband network.

CONCLUSION

The system described in this paper has evolved from the all optical-fibre trial at Milton Keynes. The advantages of different transmission media have been exploited - optical fibre in the primary links and co-axial cable in the secondary links - allowing an easy mix of services with straightforward installation. Equipment at the customer's premises has been kept to a minimum, yet a standard TV set has access to a range of interactive videotex services as well as entertainment channels. The control system, with both centralised and distributed processing, allows programme packages to be assembled to meet individual customers' needs, and inbuilt maintenance and diagnostic aids will allow speedy fault clearance. Although the cost is somewhat higher than that of a simple co-axial tree and branch network, it should be remembered that in addition to providing a wider range of revenue earning services it allows tree TV sets to be used independently, each having access to the full range of services. Furthermore, the reduction in home visits made possible by the simplified customer's installation and network resident control system, will lead to lower systems operating costs.

ACKNOWLEDGEMENTS

Development of a system of this size and complexity is a team effort, and due acknowledgement must be given to all those who have contributed. The Director of Research, British Telecom Research Labs, has also given his permission for the publication of this paper.

REFERENCES

1 Fox J R et Al: Initial Experience with the Milton Keynes Optical Fibre Cable-TV Trial. IEEE Transactions on Communications, Vol. Com-30, No 9, September 1982.

2 Ritchie W K: An Integrated Services Cable-TV Network, International Television Symposium, Montreux May 1983.

MODERN SYSTEM DESIGN CONCEPTS

Vern L. Coolidge

SCIENTIFIC-ATLANTA, INC.

ABSTRACT

The purpose of this paper is to exploit a new amplifier concept which leads to more cost effective system design through the increase of plant feeder-to-trunk ratio.

STATING THE PROBLEM

The decision to provide new or expanded cable services in any area is based on public demand and technical feasability. Weakness in either area is prone to affect the profitability of the system.

Technical feasability encompasses many engineering considerations, among which is the ability of the proposed cable network to provide quality reception throughout the area to be served. Although standards for permissable levels of noise and distortion in a system may vary, there is a limit beyond which picture quality is considered unacceptable, and it is within this limit that the cable system must be designed to perform.

Typically (and traditionally), cable networks are comprised of two or three line extender amplifiers in cascade at any system extremity, all of which are connected back to the headend through a bridger amplifier and as many trunk stations as are required to make the signal path complete. The viewer located the greatest distance from the headend receives a signal which has been amplified the greatest number of times, and consequently, this viewer receives a signal which has been subjected to the greatest exposure to noise and distortion.

The trunk portion of the system (that segment from the headend through the last trunk station) is the greatest contributor of system noise because of the lower RF levels usually found in the trunk. The distribution portion (from the bridger amplifier through the line extenders) contributes the greater to distortion because of the higher levels of RF usually carried in that segment. The right mix of low level trunk and high level distribution forms a completed system with "acceptable" levels of noise and distortion, and this has been the basis for the industry trend toward limiting the number of line extenders in cascade. So long as the high level distribution segment of the system is permitted to contribute to quality degradation at such a disproportionate rate, the system architect is "trapped" into limiting the use of line extenders in cascade.

A STEP TOWARD THE SOLUTION

Noise and distortion are predictable elements in the operating cable system so long as RF levels are maintained constant. However, fluctuations of ambient temperature affect both cable attenuation and frequency response of the system's various components. This causes RF power levels to fluctuate (in proportion to frequency), and the resulting instability makes noise and distortion levels unmanageable. The modern trunk network minimizes this effect with automatic gain and slope control in the trunk amplifier. This provides a satisfactory solution to maintaining constant RF levels on the trunk, but it stops short of giving the distribution segment the stability it needs to make its operating characteristics more predictable over the same excursions of temperature. Therefore, while automatic gain and slope control in the trunk provides an improved "total system", the system is limited to a few line extenders in cascade because of the inherent instability of the distribution segment.

ANOTHER STEP IN SOLVING THE PROBLEM

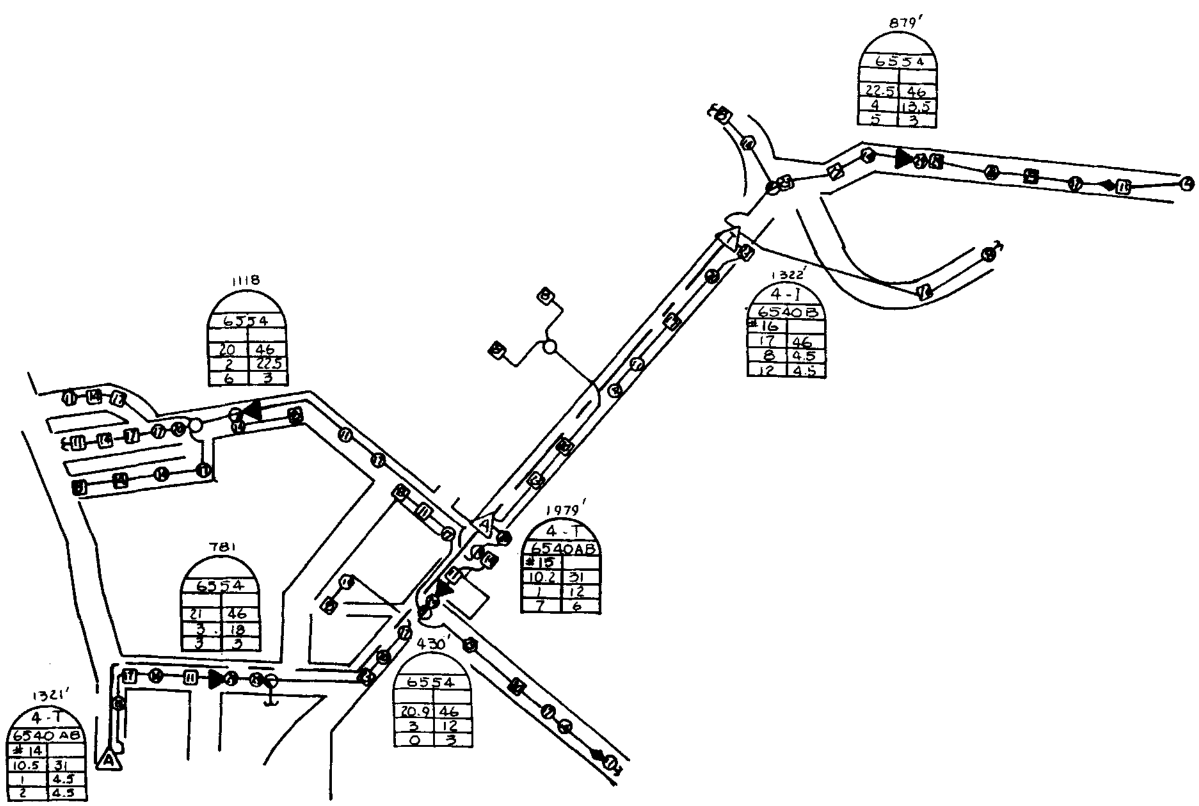
One of the measures of a system's cost effectiveness is the ratio of distribution mileage to trunk mileage. A distribution-to-trunk ratio of 3 or 4 to 1 is typical, and usually the higher this ratio, the more cost effective the plant. While this number will vary with the geography of the system and subscriber density, the only positive means of improving this distribution-to-trunk ratio is in altering the performance of the distribution amplifier and serving a given area with more distribution type plant and less trunk.

THE SOLUTION

A trunk station with automatic gain and slope control may cost 2 to 3 times the price of a typical distribution line extender without these same control features. Obviously, the investor would prefer to use more of the less expensive line extender amplifiers and fewer of the more expensive trunk stations, if he could be assured of similar performance standards. The introduction of the 6501/6502 system amplifier by Scientific-Atlanta provides that assurance to such degree that a new philosophy of system architecture is herein considered. This new amplifier concept provides pilot-referenced automatic gain control, a high degree of gain-dependent slope regulation, and a per-station cost that approximates that of the standard line extender. The advantages of its use are readily apparent in the illustrations shown.

Figure 1 is the extremity of a 16 amplifier + 1 bridger + 1 line extender cascade.

FIGURE 1



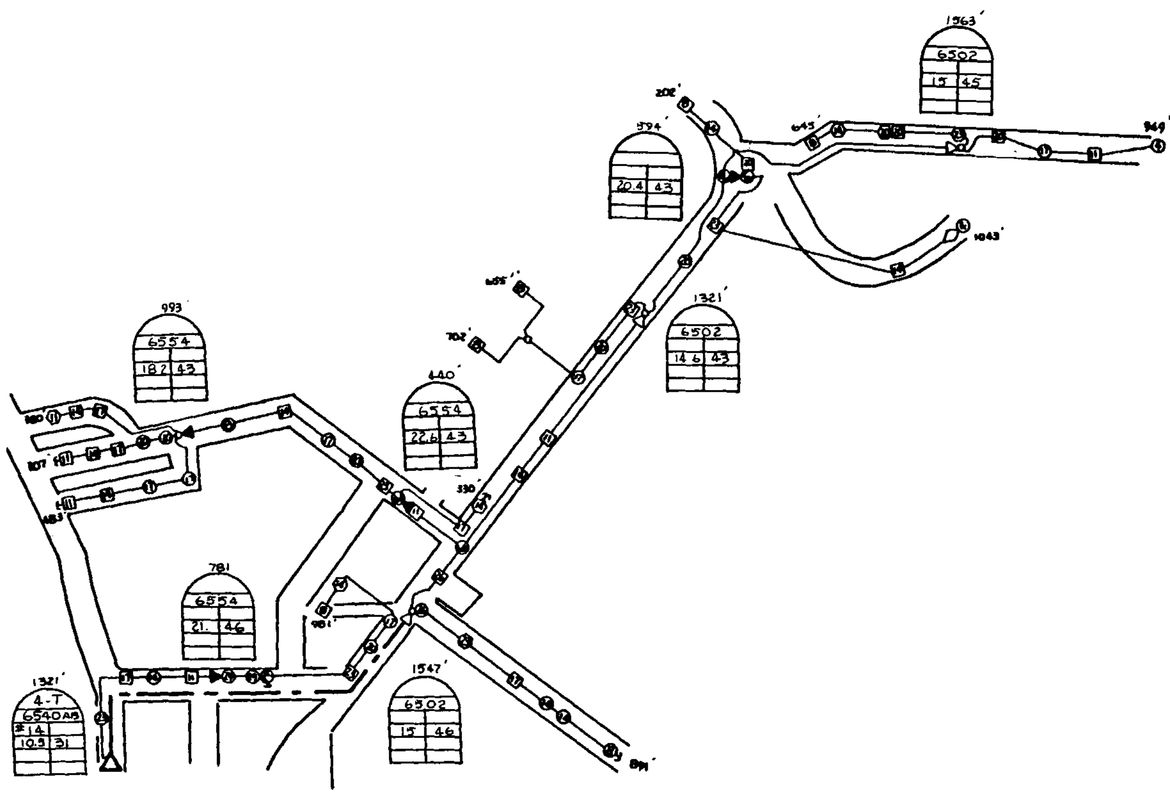
The system segment shown contains 1.9 miles of distribution plant fed by .62 miles of trunk, rendering a distribution to trunk ratio of 3:1.

With 54 channels in the bandpass of 50-400 MHz, system performance through the line extender is:

Carrier/Noise	44.3 dB
Composite Triple Beat	53.9 dB

Figure 2 is the same system redesigned with the 6502 amplifier. The terminating bridger amplifier has been eliminated, and trunk station Number 15 has been replaced by a 6502 amplifier operating at 46 dBmV output.

FIGURE 2



Performance characteristics at the same reference point are:

Carrier/Noise	45.3 dB
Composite Triple Beat	53.9 dB

The system model contains the same 1.9 miles of distribution plant with an increase in backfeeding of only 278 feet. Trunk cable useage has been reduced to .29 miles, rendering a distribution to trunk ratio of 6.5:1.

It has been stated that the distribution to trunk ratio has a direct and proportionate effect on system cost. Having demonstrated an improvement in ratio from 3:1 to 6.5:1, the resulting cost reduction may be shown.

Figure 3 deals only with those material items which were altered by redesign: cable, electronics and passives.

FIGURE 3

	Traditional Design	Revised Design
AGC Trunk Bridger (@ $725.00)	$1,450.00 (2)	$ 725.00 (1)
Terminating Bridger (@ $545.00)	545.00 (1)	---
6554 Line Extender (@ $265.00)	1,060.00 (4)	795.00 (3)
6502 AGC System Amplifier (@ $294.00)	---	882.00 (3)
2-Way Splitters (@ $18.00)	18.00 (1)	72.00 (4)
.750 GID III (@ $.35/ft.)	1,155.00 (3,300')	541.00 (1,545')
.500 GID III (@ $.165/ft.)	1,881.00 (11,400')	1,927.00 (11,678')
TOTALS	$6,109.00	$4,942.00

Cost Reduction Over 1.9 Miles:	$1,167.00
Cost Reduction Per Mile:	$ 583.50

Obviously, this cost improvement would be diluted by those system segments which don't lend themselves to redesign. Experience has shown, however, that the 6501/6502 Series AGC system amplifier may be used to advantage in a variety of applications.

MODULATION PRACTICE USED IN SATELLITE TELEVISION TRANSMISSION

GARY W. STANTON

SOUTHERN SATELLITE SYSTEMS, INC.
TULSA, OKLAHOMA 74136

ABSTRACT

In the absence of federally mandated standards for video transmission on the cable television satellites, the industry has been forced to develop it's own procedure and standards. This paper describes both the history and the current practice for modulation parameters currently used by the major program suppliers. Also described is the NCTA attempt to develop uniform standards and the reasons this has been unsuccessful. A brief description of the techniques used for additional subcarriers and stereo sound is also included.

INTRODUCTION

The advent of satellite transmission to the cable television community required the development of standards for the video transmission and for the associated program audio. In particular, the video and audio deviation parameters need to be specified. There were some guidelines created by Intelsat and others, however the equipment and needs of international transmission are different than those for domestic cable television usage. Therefore, a technology and practice evolved specifically for the cable industry.

After the initial group of programers initiated service on the Satcom system, the NCTA through the NCTA engineering committee determined it was in the best interest of the industry to develop a standard for video, program audio, and subcarrier deviations so as to create uniformity among the various satellite signals. This was considered desirable as it aided receiver manufacturers to design products that would function equally well on any transponder. Also, switching from transponder to transponder with a single receiver (Cherry picking) was common. Without uniform video and audio deviation parameters there would be objectional differences in brightness and audio levels.

For many reasons it was not possible to create a standard which everyone agreed to follow. Therefore a NCTA document was written and issued as a "Good Engineering Practice Bulletin" rather than a standard. This bulletin was subsequently withdrawn and is being replaced with a document entitled "Present Practices and Recommendations for Satellite Uplink to Cable Systems."

HISTORY

The original deviation parameters are believed to have been created as a joint effort between RCA and Scientific Atlanta. RCA was the common carrier desiring to transmit satellite video services to cable television systems and Scientific Atlanta was the manufacturer of the transmitting and receiving equipment involved in these early tests and implementations. At that time the video deviation chosen was 21.5 mHz for 100% modulation (Sync tip to reference white).

It was determined that the audio should be transmited on a separate subcarrier instead of a composite signal as is done for broadcast television. The technique chosen is identical to what is in common use on terrestrial microwave systems; in fact, terrestrial microwave subcarrier equipment was used and still is in use in many applications.

The terrestrial microwave modulators were commonly available with subcarrier frequencies of 5.8, 6.2, 6.8, and 7.2 mHz. Several of the early programers used the 6.2 mHz frequency, others used the 6.8 mHz frequency with the 6.8 mHz eventually emerging as a standard. The deviation of the main carrier by the subcarrier was chosen to be 2.0 mHz. (one side peak for 100% modulation), the same as used on terrestrial microwave.

The nominal peak deviation of the subcarrier by the audio is +-75 kHz for average program level or 0 dbm. It is broadcast practice to allow 10 db. of headroom for peaks, so this equates to a peak deviation of 237 kHz. The original satellite services such as HBO and WTCG (now WTBS) used these modulation parameters.

Unfortunately, some manufacturers did not understand the above parameters. They were never really "official", but only conveyed verbally. It was discovered that many receiver manufacturers beleived the 75 kHz to be a peak value rather than an average value and products were designed accordingly.

Most program material that is video taped does not have the 10 db peaks above average level, in fact seldom would a peak approach 6 db. (This equates to 150 kHz peak deviation). When the value of transponder space became apparent and additional subcarriers began to appear, various transponder users limited the peaks to 6 db or less by installing limiters in the transmit system. This allowed a greater number of additional subcarriers to be safely placed on the transponder.

Simultaneously, other transponder users began implementing plans to broadcast music or other audio material that required the full 10 db of headroom and the resultant 237 kHz deviation. It was with this conflict of requirements that prohibited a uniform standard from being followed.

EFFECTS ON RECEIVERS

It has not been practical to date to build a low cost satellite receiver to function optimally with the various audio deviations now in use. If a receiver is manufactured that is optimized for a peak deviation of 150 kHz, clipping will result on a signal with 237 kHz peaks. The noticeable result is distortion of letters such a "s" and "t". Conversely, a receiver optimized for higher deviations will exhibit a poor S/N when used on a lower deviation signal.

Most manufacturers attempt to build a compromise receiver, which is not optomized for either the 150 or the 237 kHz deviation. The result is that the cable operator will not obtain optimum performance. This may not be of serious importance to many cable operators as these effects are hidden by the low bandwidth of the television sound and the noise generated within the cable plant. However, some operators are now modulating the aural channel onto the FM band which has a full 15 kHz bandwidth. The effects of a non-optimized receiver can be very noticeable in this application.

Various satellite receiver manufacturers will provide audio demodulators optimized for specific services. Alternately, one can use external demodulators tailored to the specific application.

COMMON MODULATION PRACTICES

The information delineated in Table 1 was compiled from information provided by program suppliers, uplink operators, and equipment suppliers. This list is not complete, but is intended to show the various practices now being used. However, in numerous instances, it has been observed that the parameters defined by a program suppliers engineering department are not necessarily followed by the uplink operators.

The deviation parameters given in Table 1 are for the nominal test tone input level. This is complicated by the practice of many transponder users who implement various forms of audio processing. The effect is to make the effective average level to be somewhat higher than the nominal level. The peaks are generally reduced using dynamic compression techniques rather than limiting by clipping.

TABLE 1

VIDEO AND AUDIO DEVIATION

SERVICE	VIDEO	AUDIO AVERAGE	AUDIO PEAK
HBO	10.75	75	237
WGN	8.46	75	150
WTBS	9.1	75	150
USA	10.75	75	237
MTV	10.75	75	237
SHOWTIME	10.75	75	237
CNN	10.75	75	237
NCN	9.1	75	150

TABLE2

SATCOM IIIR TRANSPONDER 3

CHANNEL NUMBER	SERVICE TYPE	CENTER FREQUENCY mHz	CARRIER DEVIATION mHz
--	VIDEO	N/A	8.460
--	ENERGY DISP.	N/A	1.000
01	15 kHZ audio	5.40	.972
02	15 kHz audio	5.58	1.004
03	15 kHz audio	5.76	1.037
04	15 kHz audio	5.94	1.069
05	15 kHz audio	6.12	1.102
06	15 khz audio	6.30	1.008
07	15 kHz audio	6.48	1.037
08	15 kHz audio	6.80	2.000
09	Audio FSK	7.237	.941
10	15 kHz audio	7.38	1.328
11	15 kHz audio	7.56	1.361
12	7.5 kHz audio	7.695	1.000
13	7.5 kHz audio	7.785	1.012
14	15 kHz audio	7.920	1.426
15	7.5 kHz audio	8.055	1.047
16	7.5 kHz audio	8.145	1.059

Courtesy United Video Inc.

ADDITIONAL SUBCARRIERS

As transponder space increases in value, there has been extensive engineering effort to fully utilize the bandwidth available. Numerous subcarriers have been added to transmit stereo program audio, separate monural and stereo programing, data services, and slow scan video. Tables 2 and 3 demonstrate the usage of additional subcarriers on Satcom IIIR Transponders 3 and 6 repectively. These two transponders are the most heavily loaded with added subcarriers. There is very little commonality in the techniques used for these additional services.

TABLE 3

SATCOM IIIR TRANSPONDER 6

CHANNEL NUMBER	SERVICE TYPE	CENTER FREQUENCY mHz	CARRIER DEVIATION mHz
--	VIDEO	N/A	9.100
--	ENERGY DISP.	N/A	1.000
01	15 kHZ audio	5.40	.972
02	15 kHz audio	5.58	1.004
03	15 kHz audio	5.76	1.037
04	15 kHz audio	5.94	1.069
05	15 kHz audio	6.12	1.102
06	7.5 khz audio	6.225	.800
07	7.5 kHz audio	6.345	.810
08	7.5 kHz audio	6.435	.820
09	15 kHz audio	6.80	2.000
10	15 kHz audio	7.38	1.328
11	15 kHz audio	7.56	1.361
12	7.5 kHz audio	7.695	.980
13	7.5 kHz audio	7.785	.990

Courtesy Southern Satellite Systems

TECHNICAL CONSIDERATIONS

It has been shown that several additional subcarriers can be added with little or no effect on the video performance. When a large number of subcarriers are added, it is necessary to reduce video deviation, which effectively slightly degrades performance. From Table 1 it can be seen that the video deviations on the WGN, WTBS, and NCN transponders is lower than on several other transponders.

With respect to bandwidth, Carson's Rule is generally assumed to apply. Stated mathematically it is:

$$BW = 2 \left(F_{comp} + f_{max} \right)$$

where f_{max} is the instantaneous modulating frequency. It is considered good engineering practice to keep the bandwidth within the rated emission designator of the transmission system being used. The emmission designator of the present satellite system transponders is 36000F9, or 36 mHz bandwidth.

In the absence of rigorous theoretical analysis, one model commonly used to calculate the total deviation of multiple subcarriers is the Root Sum Square method. In this method the deviation of each component is squared; all squares are added and a square root taken on the total. The result approximates the composite peak deviation of the carrier.

Stated mathematically:

$$F_{comp} = F_v^2 + F_e^2 + F_{s1}^2 + \cdots F_{sn}^2$$

where:

F_{comp} = the composite deviation of the carrier.

F_v = the peak deviation of the video signal.

F_e = the peak deviation of the energy dispersal waveform.

F_{s1} = the peak deviation of the carrier by the first subcarrier.

F_{sn} = the peak deviation of the carrier by the nth subcarrier.

It has been determined experimentally that the RSS method is not totally accurate. For subcarriers below 7.50 mHz it appears that greater deviation is possible than would result from the calculation. For subcarrier frequencies above 7.50 mHz it appears less deviation is possible than the equation indicates. The optimum deviations are generally determined experimentally using the above equations as guidelines.

STEREO SYSTEMS

The largest single use of additional subcarriers is to provide stereo sound, either for the program audio or for discrete additional services. There are basically four types of systems in use, however there are variations in the application of a system to fit individual applications. A description of each system with pertinent parameters follows.

1. Composite Stereo System.

This was the first system in use for satellite stereo and is still used today by several program suppliers although most programers have changed to more efficient technology. The system is virtually identical to the broadcast FM stereo system, utilizing a left plus right main channel and a left minus right difference channel centered at 38kHz above the sum channel. This system produces S/N performance of 65 to 68 db on a five meter dish and midband stereo separation of 35 db.

The biggest disadvantage is the large occupied bandwidth and deviations required to obtain the above S/N performance. Deviation of the main carrier is +/- 4 mHz. Typical audio deviations are 405 kHz peak with an occupied bandwidth of approximately 900 kHz. One programer has reduced the peak deviation to 237 kHz which reduces the S/N to approximately 63 db. A second disadvantage is that the stereo separation drops significantly at band edges.

At the present time this system is being used by Home Theatre Network (HTN), and Bravo cable services.

2. Warner-amex System.

In this system, first used by Warner Amex for The Music Channel, the left plus right channel is transmitted on one subcarrier and the left minus right is transmitted on a second subcarrier. Typically, average audio deviations of +-75 kHz and peak deviations of 237 kHz are used. Deviation of the main carrier is typically +/- 2 mHz. A S/N of 70 db or greater is possible with a 5 meter dish and midband stereo seperation of 40 db is possible with bandedge separation of 35 db. This type of system can provide excellent performance if properly mantained and adjusted. The major problem is the need to maintain the phase and amplitude characteristics of the two channels as identical as possible. Failure to do so results in loss of stereo separation.

At present this system is being used by The Music Channel (MTV), The Movie Channel, and The Disney Channel.

3. Times Mirror System.

In this stereo system the sum left plus right signal is transmitted on the normal 6.8 mHz subcarrier. In addition, the left channel is transmitted at 5.8 mHz and the right subcarrier is transmitted at 6.2 mHz. Deviations of +-75 kHz average and 237 kHz peak are used. S/N is typically 65 to 68 db and stereo seperation is almost unlimited. This system provides the best performance, but is also the most wasteful of bandwidth and transponder power.

This system is used by the ARTS and SPOTLIGHT programing services.

4. Wegener Communications System

The Wegener Communications System(WCI) is unique in that it utilizes low deviation narrow band subcarriers. To compensate for the lower S/N which one may expect from the low deviations, a compounding system is utilized. The system is similar to Dolby except that the preemphasis starts as low as 50 Hz and extends over the entire frequency spectrum. The result is a highly efficient transponder usage. Tables 2 and 3 demonstrate the use of this system for all except the 6.8 mHz program audio.

In this system, separate left and right channels are transmitted on separate subcarriers. The typical occupied bandwidth for a 15 kHz channel is only 130 kHz instead of 500 Khz for any of the above methods. Also, the main carrier deviation is nominaly 1.0 mHz instead of 2.0 used for the other systems. S/N performance of 68 to 70 db results along with unlimited stereo separation. In practice, the stereo separation is about 30 db. due to the conversion to the standard broadcast FM format for transmission over the cable system.

At the present time this system is used by Southern Satellite Systems (WTBS), United video (WGN), National Christan Network, and PTL.

CONCLUSIONS

There are some differences in the parameters used for the transmission of the program associated audio. Although adequate performance can be obtained with a general purpose receiver, optimum performance requires a receiver tailored to the specific service desired. The reception of subcarriers requires special equipment in all cases as there is a wide variety of systems and techniques in use.

MULTI-CARRIER OPERATION OF SPACENET TRANSPONDERS FOR FM/TV APPLICATIONS

R. J. Hall

SOUTHERN PACIFIC SATELLITE COMPANY
McLean, Virginia

ABSTRACT

System trade-offs for FM/TV multi-carrier operation for each of the three classes of SPACENET transponders (narrow C-Band, wide C-Band and Ku-Band) are examined. A variety of link configurations are constructed, assuming representative earth station characteristics (antenna diameter, HPA power, LNA temperature, etc.), to provide link performance estimates which satisfy a variety of user requirements. Results indicate that multi-carrier use of the SPACENET transponders may be a cost effective alternative to single-carrier use of two transponders.

INTRODUCTION

The objective of this paper is to present representative link performance characteristics (C/N, S/N) for dual-carrier-per-transponder use of SPACENET transponders. This is accomplished by examining each class of transponders for various uplink and downlink earth station configurations for a variety of user requirements.

In 1984, the Southern Pacific Satellite Company will be launching two communications satellites, SPACENET I and SPACENET II, into geostationary orbit at 119°W and 70°W, respectively. Launch of a third SPACENET satellite is planned for 1985.* These satellites will operate at both C-Band (4/6 GHz) and Ku-Band (12/14 GHz) and will provide video programming distribution capacity, as well as voice and data transmission services, to a variety of customers.

This capacity will be provided among three classes of transponders:

1. Narrow C-Band transponders (12 @ 36 MHz)
2. Wide C-Band transponders (6 @ 72 MHz)
3. Ku-Band transponders (6 @ 72 MHz)

The frequency and polarization plan for the SPACENET transponders is depicted in Figure 1.

Narrow C-Band Transponders

The narrow C-Band class of transponders is comprised of twelve operational and two spare RCA solid-state power amplifiers (SSPA's). Because of their inherent linearity, SSPA's may be operated near their single-carrier operating point for multiple-carrier applications without incurring harmful intermodulation interference or crosstalk.

Wide C-Band and Ku-Band Transponders

The SPACENET satellites will operate with six wide C-Band transponders and six Ku-Band transponders. Seven-for-six redundancy is provided for both of these classes of transponders. These transponders will utilize 16-watt TWTA's manufactured by Hughes Electron Dynamics Division. The 72-MHz of bandwidth available using these transponders provides ample spectrum for the transmission of two "full transponder" (i.e., FM deviation = 10.75 MHz) video signals without incurring harmful intermodulation and crossmodulation interference and using only a moderate level of input and output backoff.

SUMMARY OF RESULTS

The performance results for the various uplink and downlink earth station configurations considered in the link analyses are provided in Table 1. As shown, the clear weather video signal-to-noise ratio's for these configurations range from 41.7 dB (for "half-transponder" video using a SPACENET narrow C-Band transponder) to 50.7 and 53.7 dB (for "full-transponder" video using the SPACENET wide C-Band and Ku-Band transponders, respectively). For comparison, expected single-carrier performance using the SPACENET narrow C-Band transponders is provided.

The carrier-to-noise and signal-to-noise ratio's shown are expected to be exceeded for actual links, since the predicted adjacent-satellite interference levels incorporated into the calculation of link performance were based on worst case orbital spacing and geometric assumptions, discussed in the final section of this paper.

* On April 27, 1983, the FCC adopted a revised orbital deployment plan. This plan provides for SPACENET I deployment at 122°W, SPACENET II deployment at 69°W and SPACENET III deployment at 91°W.

For dual-carrier "half-transponder" video transmission using the narrow C-Band transponders, typical receive earth station antenna diameters on the order of 7-meters would be required to achieve video signal-to-noise ratios greater than 41 dB and threshold extension would be required.

Transmission of "full-transponder" video signals using the SPACENET wide C- and Ku-Band classes of transponders provide higher quality signals (video S/N = 49-51 dB) than the half-transponder signals available using narrow C-Band transponders and, in general, provide only slightly lower performance (3 dB) than for narrow C-Band single-carrier transmissions.

DESCRIPTION OF THE ANALYSIS

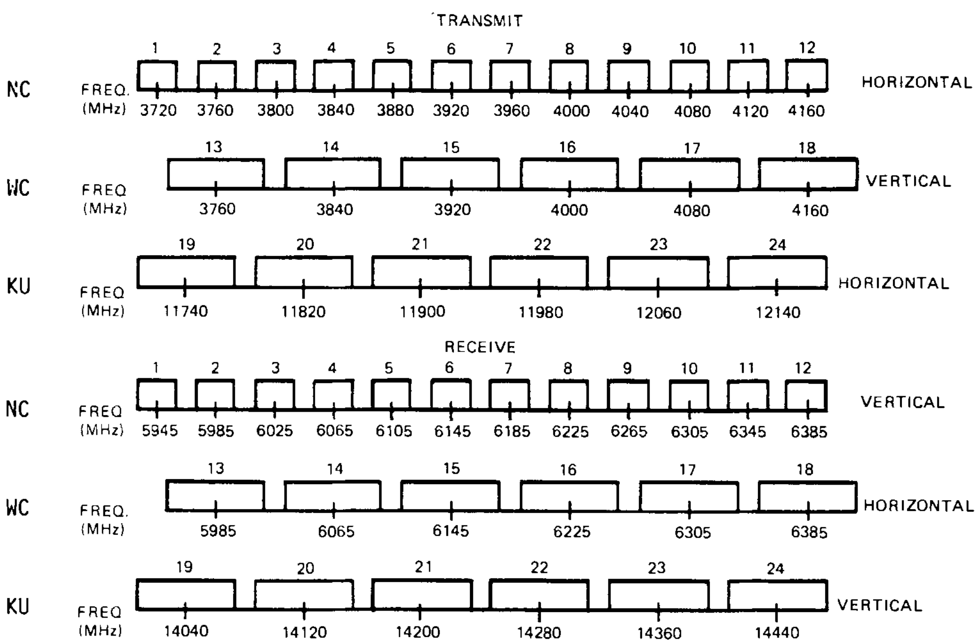
In this section, (1) a list of the basic assumptions used in the analysis is provided, (2) the assumed and calculated link performance parameters are identified, and (3) the analysis results for each class of transponder are discussed.

Basic Assumptions Used in the Analysis

The following assumptions are incorporated into the various link performance analyses:

° Video Peak Deviation: 10.75 MHz, for full-transponder video transmission and 6.7 MHz for half-transponder video transmission
° IF Bandwidth: 32.5 MHz, for full-transponder video transmission and 17.5 MHz for half-transponder video transmission
° Required Dual-Carrier Input Backoff: 1 dB assumed for narrow C-Band transponders and 2.0 dB for wide C-Band and Ku-Band transponders.
° Resultant Dual-Carrier Output Backoff: 1 dB for narrow C-Band transponders and 1.5 dB for wide C-Band and Ku-Band transponders

FIGURE 1. SPACENET FREQUENCY AND POLARIZATION PLAN



NC - Narrow C-Band
WC - Wide C-Band
KU - Ku-Band

TABLE 1

SUMMARY TABLE OF SPACENET SINGLE AND MULTI-CARRIER LINK RESULTS

EARTH STATION DIAMETER (m)		NARROW C-BAND CNR/SNR		WIDE C-BAND CNR/SNR	KU-BAND CNR/SNR
UPLINK	DOWNLINK	SINGLE	DUAL	DUAL	DUAL
10	10	16.2/53.8	12.6/43.4	13.1/50.7	--
10	7	14.6/52.2	10.9/41.7*	11.7/49.3*	--
7	7	14.6/52.2	10.9/41.7*	11.7/49.3*	--
7	5	12.4/50.0	--	9.8/47.3*	--
7.7	7.7	--	--	--	16.1/53.7*
5.5	5.5	--	--	--	14.5/52.1*

* Assumes use of threshold extension

Parameters Used or Derived in the Link Analyses

The following parameters of operation are used in calculating the link performance for the various earth station configurations:

° Uplink location
° Downlink location
° Saturation flux density (dBW/m^2)
° EIRP at saturation (dBW)
° EIRP/carrier (dBW)
° Required uplink high power amplifier (HPA) power (Watts)
° Uplink carrier-to-noise ratio (dB)
° Downlink carrier-to-noise ratio (dB)
° Link carrier-to-noise ratio (dB)
° Link margin above threshold (dB)
° Video signal-to-noise ratio (dB)

Each of these items is discussed below.

Uplink Location - Three uplink earth station locations are considered:

A. New York, NY
B. Houston, TX
C. Los Angeles, CA

Representative uplink earth stations at these locations are assumed to be accessing a SPACENET satellite at 119°W.

Downlink Location - The three downlink earth station locations considered are:

A. New York, NY
B. Houston, TX
C. Los Angeles, CA

Representative downlink earth stations at these locations are assumed to be accessing a SPACENET satellite at 119°W.

Saturation Flux Density - This parameter identifies the expected required flux density for transponder saturation from an earth station at each of the various uplink locations.

For each of the C-Band transponders, the nominal power flux levels required at the satellite to achieve transponder saturation are ground commandable to -80 dBW/m^2 or -86 dBW/m^2. These levels correspond to narrow C-Band transponder G/T levels of -5 dB/K and wide C-Band transponder G/T levels of -2 dB/K. For each of the Ku-Band transponders, the nominal levels required are ground commandable to -74 dBW/m^2, -80 dBW/m^2, or -86 dBW/m^2. These levels correspond Ku-Band spacecraft G/T levels of -2 dB/K.

Nominal SPACENET satellite G/T contour levels are depicted in Figure 2.

EIRP at Saturation - This parameter identifies the expected spacecraft downlink EIRP at saturation for each of the downlink earth station locations considered. Nominal SPACENET satellite EIRP contour levels are depicted in Figure 3.

EIRP/Carrier - This parameter identifies the power-shared EIRP-per-video-carrier and also incorporates any resultant output backoff required to preclude harmful intermodulation interference.

Required HPA Power - This parameter depicts the high power amplifier power required to satisfy the saturation flux density requirements (including input backoff) and provide a sufficient uplink carrier-to-noise ratio. The equation and corresponding assumptions used to calculate this parameter are described in detail in the Appendix.

FIGURE 2. SATELLITE G/T CONTOURS FOR THREE CLASSES OF SPACENET TRANSPONDERS

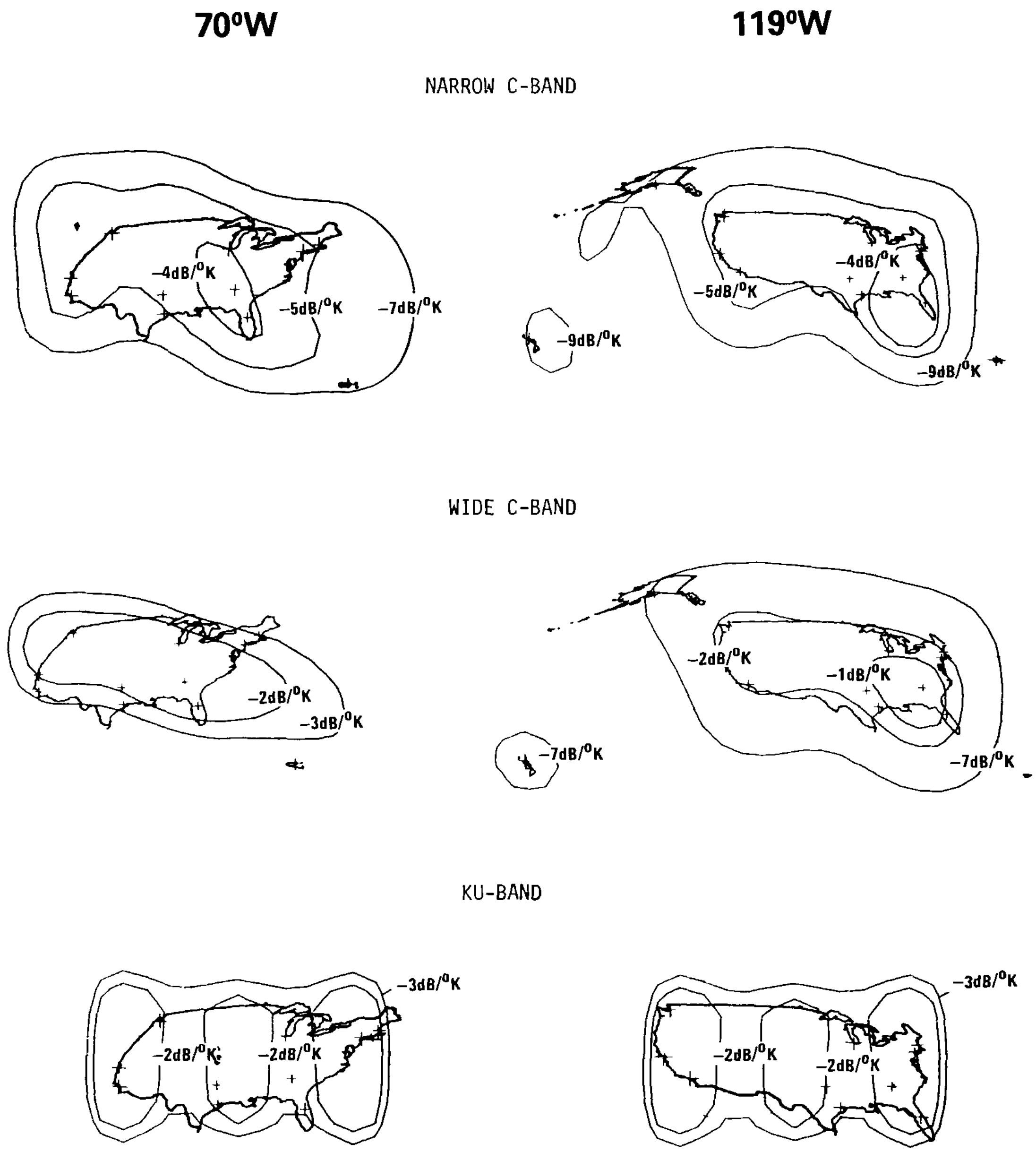
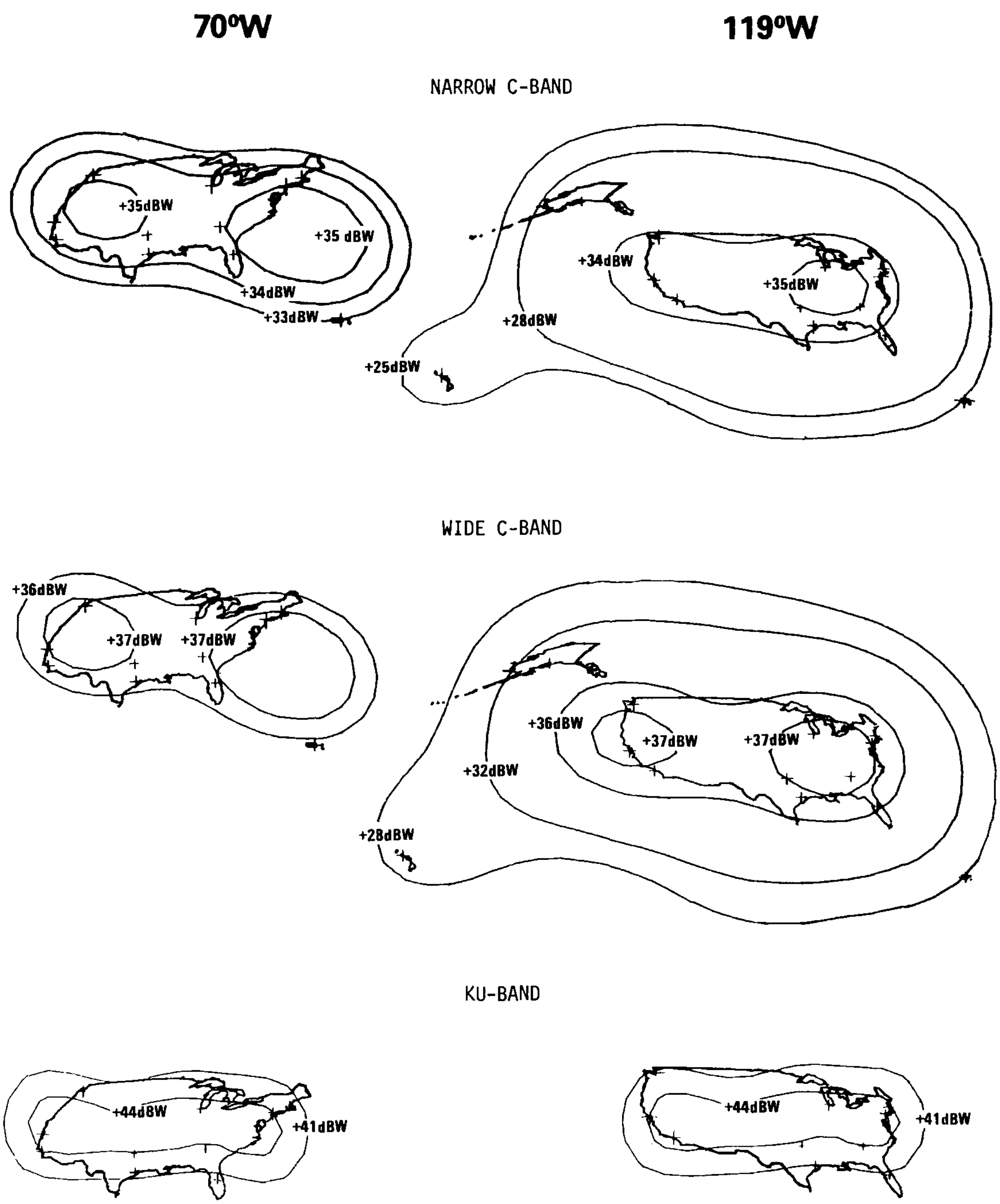


FIGURE 3. SATELLITE EIRP CONTOURS FOR THREE CLASSES OF SPACENET TRANSPONDERS



Uplink Carrier-to-Noise Ratio - This uplink performance characteristic is calculated based upon the earth station EIRP (per carrier), transmission losses, and satellite G/T (which is referenced to the required saturation flux density, described previously). The equation and assumptions used for its calculation are provided in the Appendix.

Downlink Carrier-to-Noise Ratio - This downlink performance characteristic is calculated based upon the spacecraft EIRP (per carrier), transmission losses, and earth station G/T. The equation and assumptions used for its calculation are provided in the Appendix.

Link Carrier-to-Noise Ratio - This performance characteristic is calculated from the power summation of the uplink carrier-to-noise ratio, the downlink carrier-to-noise ratio and all interference contributions. The equations and assumptions used for its calculation are further detailed in the Appendix.

Link Margin Above Threshold - This value was calculated by subtracting the FM threshold carrier-to-noise ratio from the calculated link carrier-to-noise ratio described above. Normally, a 12-dB carrier-to-noise FM threshold was assumed. For certain link configurations, threshold extension was assumed. For these cases, the margin was calculated based on a threshold carrier-to-noise ratio of 8 dB.

Video Signal-to-Noise Ratio - This performance parameter was calculated based upon the calculated link carrier-to-noise ratio (described above) and the FM deviation that was assumed. The equation and assumptions used in its calculation are detailed in the Appendix.

Narrow C-Band Transponder Analysis

Table 2 lists representative performance characteristics for three transmit/receive (T/R) C-Band earth stations. The characteristics of these earth stations are used in the examination of FM/TV link performance for both the narrow C-Band and wide C-Band classes of transponders.

Single-Carrier Case - For reference, a single-carrier FM/TV link configuration is considered for the narrow C-Band transponder link analysis. The link consists of a 7-meter uplink earth station and a 5-meter downlink earth station. The link performance results for this configuration are depicted in Table 3. As shown, HPA powers from 1175-1300 watts are required, providing an uplink carrier-to-noise ratio of 25.3 dB. The resultant total carrier-to-noise ratio is 12.4 dB, providing a clear weather video S/N of 50.0 dB. Use of the 7-meter receive earth station characterized in Table 2 will increase the $(C/N)_t$ to 14.6 dB and provide a "studio quality" video S/N of 52.2 dB.

TABLE 2

C-BAND EARTH STATION CHARACTERISTICS

Earth Station Diameter/ Type	Antenna Gain (dBi)	LNA Temp. (K)	Station G/T (dB/K) (@ 20° elev. & clear)
10-meter T/R	50.85 @ 3.95 GHz	100	29.4
	53.5 @ 6.175 GHz	-	-
7-meter T/R	47.5 @ 3.95 GHz	80	26.9
	49.4 @ 6.175 GHz	-	-
5-meter T/R	44.5 @ 3.95 GHz	80	24.0
	47.3 @ 6.175 GHz	-	-

TABLE 3

SINGLE-CARRIER NARROW C-BAND LINK PERFORMANCE: 7-m. UPLINK EARTH STATION/5-m. DOWNLINK EARTH STATION.

UPLINK LOCATION	DOWNLINK LOCATION	SATURATION FLUX DENSITY (dBW/m^2)	SATURATED EIRP (dBW)	EIRP/ CARRIER (dBW)	HPA POWER REQUIRED (Watts)	$(C/N)_u$	$(C/N)_d$	$(C/N)_t$	LINK MARGIN (dB)	VIDEO S/N (dB) (CLEAR)
NY	NY	-86.6	34.4	34.4	1175	25.3	14.6	12.4	0.4	50.0
NY	Houston	-86.6	34.4	34.4	1175	25.3	14.6	12.4	0.4	50.0
NY	LA	-86.6	34.4	34.4	1175	25.3	14.6	12.4	0.4	50.0
Houston	NY	-86.5	34.4	34.4	1200	25.3	14.6	12.4	0.4	50.0
Houston	Houston	-86.5	34.4	34.4	1200	25.3	14.6	12.4	0.4	50.0
Houston	LA	-86.5	34.4	34.4	1200	25.3	14.6	12.4	0.4	50.0
LA	NY	-86.2	34.4	34.4	1300	25.3	14.6	12.4	0.4	50.0
LA	Houston	-86.2	34.4	34.4	1300	25.3	14.6	12.4	0.4	50.0
LA	LA	-86.2	34.4	34.4	1300	25.3	14.6	12.4	0.4	50.0

SATELLITE @ 119°W

Dual Carrier Case - For the dual-carrier narrow C-Band case, two link configurations are considered: a 10-meter transmit earth station to a 10-meter receive earth station link and a 7-meter transmit earth station to a 7-meter receive earth station link.

Table 4 depicts the link performance parameters for the first configuration -- a 10-meter uplink earth station and a 10-meter downlink earth station. For this configuration, HPA powers of 375-400 watts are required. The resultant clear weather total carrier-to-noise and video signal-to-noise ratio levels are 12.6 dB and 43.4 dB, respectively.

For the second configuration, depicted in Table 5, 7-meter uplink and downlink earth stations are assumed. For this example, higher uplink HPA powers are required (950-1025 watts). A $(C/N)_t$ of 10.9 dB results and threshold extension (down to 8.0 dB) provides a 2.9 dB margin above threshold. The corresponding video S/N (clear), however, is only 41.7 dB, which may only be acceptable for certain applications.

For both configurations above, the substantially lower S/N levels (in comparison with the single-carrier narrowband case) are a result of the combined effects of power sharing, input backoff and reduced FM improvement (a result of the reduced deviation which must be employed to meet RF bandwidth constraints). The link margin values may be increased through the employment of threshold extension.

TABLE 4

DUAL-CARRIER NARROW C-BAND LINK PERFORMANCE: 10-m. UPLINK EARTH STATION/10-m. DOWNLINK EARTH STATION

UPLINK LOCATION	DOWNLINK LOCATION	SATURATION FLUX DENSITY (dBW/m^2)	SATURATED EIRP (dBW)	EIRP/ CARRIER (dBW)	HPA POWER REQUIRED (Watts)	$(C/N)_u$	$(C/N)_d$	$(C/N)_t$	LINK MARGIN (dB)	VIDEO S/N (dB) (CLEAR)
NY	NY	-86.6	34.4	30.4	375	21.3	16.0	12.6	0.6	43.4
NY	Houston	-86.6	34.4	30.4	375	21.3	16.0	12.6	0.6	43.4
NY	LA	-86.6	34.4	30.4	375	21.3	16.0	12.6	0.6	43.4
Houston	NY	-86.5	34.4	30.4	375	21.3	16.0	12.6	0.6	43.4
Houston	Houston	-86.5	34.4	30.4	375	21.3	16.0	12.6	0.6	43.4
Houston	LA	-86.5	34.4	30.4	375	21.3	16.0	12.6	0.6	43.4
LA	NY	-86.2	34.4	30.4	400	21.3	16.0	12.6	0.6	43.4
LA	Houston	-86.2	34.4	30.4	400	21.3	16.0	12.6	0.6	43.4
LA	LA	-86.2	34.4	30.4	400	21.3	16.0	12.6	0.6	43.4

SATELLITE @ 119°W

TABLE 5

DUAL-CARRIER NARROW C-BAND LINK PERFORMANCE: 7-m. UPLINK EARTH STATION/7-m. DOWNLINK EARTH STATION

UPLINK LOCATION	DOWNLINK LOCATION	SATURATION FLUX DENSITY (dBW/m^2)	SATURATED EIRP (dBW)	EIRP/ CARRIER (dBW)	HPA POWER REQUIRED (Watts)	$(C/N)_u$	$(C/N)_d$	$(C/N)_t$	LINK * MARGIN (dB)	VIDEO S/N (dB) (CLEAR)
NY	NY	-86.6	34.4	30.4	950	21.3	13.5	10.9	2.9	41.7
NY	Houston	-86.6	34.4	30.4	950	21.3	13.5	10.9	2.9	41.7
NY	LA	-86.6	34.4	30.4	950	21.3	13.5	10.9	2.9	41.7
Houston	NY	-86.5	34.4	30.4	975	21.3	13.5	10.9	2.9	41.7
Houston	Houston	-86.5	34.4	30.4	975	21.3	13.5	10.9	2.9	41.7
Houston	LA	-86.5	34.4	30.4	975	21.3	13.5	10.9	2.9	41.7
LA	NY	-86.2	34.4	30.4	1025	21.3	13.5	10.9	2.9	41.7
LA	Houston	-86.2	34.4	30.4	1025	21.3	13.5	10.9	2.9	41.7
LA	LA	-86.2	34.4	30.4	1025	21.3	13.5	10.9	2.9	41.7

SATELLITE @ 119°W

* Assumes threshold extension to permit operation at $(C/N)t \geq 8$ dB

Wide C-Band Transponder Analysis

For the dual-carrier wide C-Band analysis, three configurations are examined, based on the earth station characteristics previously-listed in Table 2.

° 10-meter uplink e.s./10-meter downlink e.s.
° 7-meter uplink e.s./7-meter downlink e.s.
° 7-meter uplink e.s./5-meter downlink e.s.

For all three configurations above, transponder input and output backoff levels of 2 dB and 1.5 dB, respectively, are assumed to maintain an acceptable level of carrier-to-intermodulation interference.

Table 6 depicts the link performance results for the first configuration, a 10-meter uplink earth station and a 10-meter downlink earth station. This configuration provides a clear weather $(C/N)_t$ of 13.1 dB and a video S/N of 50.7 dB. HPA powers on the order of 300-350 watts are required.

Table 7 depicts link performance for the second configuration, a 7-meter uplink earth station and a 7-meter downlink earth station. The resulting required HPA powers range from 750-875 watts. Threshold extension is assumed, and the resultant clear weather $(C/N)_t$ and video S/N are 11.7 dB and 52.0 dB, respectively, for all links examined.

The third configuration is that of a 7-meter uplink earth station and a 5-meter downlink earth station. The link performance predictions for this configuration are shown in Table 8. Threshold extension is assumed and a $(C/N)_t$ of 9.7 dB is predicted, with a corresponding S/N of 47.3 dB.

Ku-Band Transponder Analysis

Table 9 lists representative earth station performance characteristics for two T/R Ku-Band earth stations that are presently manufactured.

TABLE 6

DUAL-CARRIER WIDE C-BAND LINK PERFORMANCE: 10-m UPLINK EARTH STATION/10-m DOWNLINK EARTH STATION

UPLINK LOCATION	DOWNLINK LOCATION	SATURATION FLUX DENSITY (dBW/m^2)	SATURATED EIRP (dBW)	EIRP/ CARRIER (dBW)	HPA POWER REQUIRED (Watts)	$(C/N)_u$	$(C/N)_d$	$(C/N)_t$	LINK MARGIN (dB)	VIDEO S/N (dB) (CLEAR)
NY	NY	-86.0	36.4	31.9	350	23.3	17.5	13.1	1.1	50.7
NY	Houston	-86.0	36.4	31.9	350	23.3	17.5	13.1	1.1	50.7
NY	LA	-86.0	36.4	31.8	350	23.3	17.4	13.1	1.1	50.7
Houston	NY	-86.6	36.4	31.9	300	23.3	17.5	13.1	1.1	50.7
Houston	Houston	-86.6	36.4	31.9	300	23.3	17.5	13.1	1.1	50.7
Houston	LA	-86.6	36.3	31.8	300	23.3	17.4	13.1	1.1	50.7
LA	NY	-85.9	36.4	31.9	350	23.3	17.5	13.1	1.1	50.7
LA	Houston	-85.9	36.4	31.9	350	23.3	17.5	13.1	1.1	50.7
LA	LA	-85.9	36.3	31.8	350	23.3	17.4	13.1	1.1	50.7

SATELLITE @ 119°W

TABLE 7

DUAL-CARRIER WIDE C-BAND LINK PERFORMANCE: 7-m UPLINK EARTH STATION/7-m DOWNLINK EARTH STATION

UPLINK LOCATION	DOWNLINK LOCATION	SATURATION FLUX DENSITY (dBW/m^2)	SATURATED EIRP (dBW)	EIRP/ CARRIER (dBW)	HPA POWER REQUIRED (Watts)	$(C/N)_u$	$(C/N)_d$	$(C/N)_t$	LINK* MARGIN (dB)	VIDEO S/N (dB) (CLEAR)
NY	NY	-86.0	36.4	31.9	850	23.3	15.0	11.7	3.7	49.3
NY	Houston	-86.0	36.4	31.9	850	23.3	15.0	11.7	3.7	49.3
NY	LA	-86.0	36.3	31.8	850	23.3	14.9	11.7	3.7	49.3
Houston	NY	-86.6	36.4	31.9	750	23.3	15.0	11.7	3.7	49.3
Houston	Houston	-86.6	36.4	31.9	750	23.3	15.0	11.7	3.7	49.3
Houston	LA	-86.6	36.3	31.8	750	23.3	14.9	11.7	3.7	49.3
LA	NY	-85.9	36.4	31.9	875	23.3	15.0	11.7	3.7	49.3
LA	Houston	-85.9	36.4	31.9	875	23.3	15.0	11.7	3.7	49.3
LA	LA	-85.9	36.3	31.8	875	23.3	14.9	11.7	3.7	49.3

* Assumes threshold extension to permit operation at $(C/N)_t \geq 8$ dB.

SATELLITE @ 119°W

TABLE 8

DUAL-CARRIER WIDE C-BAND LINK PERFORMANCE: 7-m. UPLINK EARTH STATION/5-m. DOWNLINK EARTH STATION

UPLINK LOCATION	DOWNLINK LOCATION	SATURATION FLUX DENSITY (dBW/m^2)	SATURATED EIRP (dBW)	EIRP/ CARRIER (dBW)	HPA POWER REQUIRED (Watts)	$(C/N)_u$	$(C/N)_d$	$(C/N)_t$	LINK * MARGIN (dB)	VIDEO S/N (dB) (CLEAR)
NY	NY	-86.0	36.4	31.9	850	23.3	12.1	9.7	1.7	47.3
NY	Houston	-86.0	36.4	31.9	850	23.3	12.1	9.7	1.7	47.3
NY	LA	-86.0	36.3	31.8	850	23.3	12.0	9.7	1.7	47.3
Houston	NY	-86.6	36.4	31.9	750	23.3	12.1	9.7	1.7	47.3
Houston	Houston	-86.6	36.4	31.9	750	23.3	12.1	9.7	1.7	47.3
Houston	LA	-86.6	36.3	31.8	750	23.3	12.0	9.7	1.7	47.3
LA	NY	-85.9	36.4	31.9	875	23.3	12.1	9.7	1.7	47.3
LA	Houston	-85.9	36.4	31.9	875	23.3	12.1	9.7	1.7	47.3
LA	LA	-85.9	36.3	31.8	875	23.3	12.0	9.7	1.7	47.3

SATELLITE @ 119°W

* Assumes threshold extension to permit operation at $(C/N)_t \geq 8$ dB.

TABLE 9

KU-BAND EARTH STATION CHARACTERISTICS

EARTH STATION DIAMETER/TYPE	ANTENNA GAIN (dBi)	LNA TEMPERATURE (K)	STATION G/T (dB/K) (@ 20° ELEV. & CLEAR)
7.7-meter T/R	57.9 @ 11.95 GHz	180	33.8
	59.2 @ 14.25 GHz	-	-
5.5-meter T/R	55.0 @ 11.95 GHz	180	30.9
	56.3 @ 14.25 GHZ	-	-

To provide a sufficient uplink carrier-to-noise ratio, 6-dB transponder input gain attenuation is assumed for all configurations examined for the Ku-Band class of transponders. Threshold extension is also assumed for all cases to provide sufficient fade margin.

For the dual-carrier Ku-Band analysis, the following configurations are examined:

° 7.7-meter uplink e.s./7.7-meter downlink e.s.
° 5.5-meter uplink e.s./5.5-meter downlink e.s.

For the first configuration above, the link performance parameters and results are depicted in Table 10. Required HPA powers range from 300-450 watts and provide uplink carrier-to-noise ratios of 22.0 dB. For New York and Los Angeles downlinks, a clear weather $(C/N)_t$ of 16.1 dB results along with a video S/N of 53.7 dB. For a Houston downlink, a clear weather $(C/N)_t$ of 14.2 dB is provided along with a video S/N of 51.8 dB.

Link performance predictions for the second configuration, a 5.5-meter uplink earth station and a 5.5-meter downlink earth station, are depicted in Table 11. To provide equivalent uplink performance as a 7.7-meter uplink earth station, HPA powers from 575-875 watts are required. Overall link margins are not high as for the first configuration, however. Clear weather video S/N's of 52.1 dB are predicted for New York and Los Angeles, while an S/N S/N (clear) of 49.8 dB is predicted at Houston.

TABLE 10

DUAL-CARRIER KU-BAND LINK PERFORMANCE: 7.7-m. UPLINK EARTH STATION/7.7-m. DOWNLINK EARTH STATION

UPLINK LOCATION	DOWNLINK LOCATION	SATURATION [1] FLUX DENSITY (dBW/m^2)	SATURATED EIRP (dBW)	EIRP/ CARRIER (dBW)	HPA POWER REQUIRED (Watts)	$(C/N)_u$	$(C/N)_d$	$(C/N)_t$	LINK [2] MARGIN (dB)	VIDEO S/N (dB) (CLEAR)
NY	NY	-81.0	44.0	39.5	300	22.0	20.0	16.1	8.1	53.7
NY	Houston	-81.0	40.4	35.9	300	22.0	16.4	14.2	6.2	51.8
NY	LA	-81.0	44.0	39.5	300	22.0	20.0	16.1	8.1	53.7
Houston	NY	-79.2	44.0	39.5	450	22.0	20.0	16.1	8.1	53.7
Houston	Houston	-79.2	40.4	35.9	450	22.0	16.4	14.2	6.2	51.8
Houston	LA	-79.2	44.0	39.5	450	22.0	20.0	16.1	8.1	53.7
LA	NY	-79.6	44.0	39.5	425	22.0	20.0	16.1	8.1	53.7
LA	Houston	-79.6	40.4	35.9	425	22.0	16.4	14.2	6.2	51.8
LA	LA	-79.6	44.0	39.5	425	22.0	20.0	16.1	8.1	53.7

SATELLITE @ 119°W

[1] 6-dB transponder input gain attenuation employed
[2] Assumes threshold extension to permit operation at $(C/N)_t \geq 8$ dB.

TABLE 11

DUAL-CARRIER KU-BAND LINK PERFORMANCE: 5.5-m. UPLINK EARTH STATION/5.5-m. DOWNLINK EARTH STATION

UPLINK LOCATION	DOWNLINK LOCATION	SATURATION [1] FLUX DENSITY (dBW/m^2)	SATURATED EIRP (dBW)	EIRP/ CARRIER (dBW)	HPA POWER REQUIRED (Watts)	$(C/N)_u$	$(C/N)_d$	$(C/N)_t$	LINK [2] MARGIN (dB)	VIDEO S/N (dB) (CLEAR)
NY	NY	-81.0	44.0	39.5	575	22.0	17.1	14.5	6.5	52.1
NY	Houston	-81.0	40.4	35.9	575	22.0	13.5	12.2	4.2	49.8
NY	LA	-81.0	44.0	39.5	575	22.0	17.1	14.5	6.5	52.1
Houston	NY	-79.2	44.0	39.5	875	22.0	17.1	14.5	6.5	52.1
Houston	Houston	-79.2	40.4	35.9	875	22.0	13.5	12.2	4.2	49.8
Houston	LA	-79.2	44.0	39.5	875	22.0	17.1	14.5	6.5	52.1
LA	NY	-79.6	44.0	39.5	800	22.0	17.1	14.5	6.5	52.1
LA	Houston	-79.6	40.4	35.9	800	22.0	13.5	12.2	4.2	49.8
LA	LA	-79.6	44.0	39.5	800	22.0	17.1	14.5	6.5	52.1

[1] 6-dB transponder input gain attenuation employed.
[2] Assumes threshold extension to permit operation at $(C/N)_t \geq 8$ dB.

SATELLITE @ 119°W

OTHER CONSIDERATIONS

Adjacent-Satellite Interference Levels

For the consideration of adjacent-satellite interference, two satellites are assumed to be located 2° on either side of the SPACENET satellite. These "worst-case" adjacent satellite interference levels are based on interference signals that are assumed to be co-frequency and co-polarized to the SPACENET signals. In addition, geocentric angles were assumed in the calculation of off-axis earth station antenna gain. As a result, actual link performance will exceed the pessimistic values shown in the tables.

Downlink Rain Fade Effects and Link Availability at Ku-Band

The effect of uplink fading on the downlink is basically a function of the point of operation on the transponder power transfer characteristic curve (specifically, the increase or decrease in downlink power due to variation in received uplink power levels). Uplink fading can be controlled to a significant extent by monitoring the received downlink power levels at the uplink location and compensating for rain attenuation by increasing the uplink power.

Table 14 depicts the attenuation due to down link rain fading that is not predicted to be exceeded for the availabilities shown. These predictions are based on Rice-Holmberg rain statistics and Olsen rain attenuation parameters.[1,2] The reader is referred to References 4 and 5 for a detailed description of their derivation. Basically, the statistical model by Rice and Holmberg calculates the percentage of an average year for which the rainfall rate exceeds a give rain rate R, based on the average annual rainfall and relative percentage of annual rain produced by thunderstorms for a particular geographic location.

TABLE 12

KU-BAND DOWNLINK RAIN ATTENUATION, IN dB

	AVAILABILITY (%)			
DOWNLINK LOCATION	99.9	99.8	99.7	99.5
New York	3.3	2.3	1.9	1.3
Houston	5.4	2.4	1.6	0.9
Los Angeles	1.2	0.7	0.5	0.3

SATELLITE @ 119°W

Sufficient link margin is required to accommodate the values shown in Table 14 for a particular desired availability as well as the additional margin required to accommodate the effective increase in the receive earth station system noise temperature as a function of rain fading.

ALTERNATIVES FOR MULTI-CARRIER USE OF THE SPACENET TRANSPONDERS

In addition to the straight-forward approach which has been addressed in this paper for the transmission of multi-carrier FM/TV signals on the SPACENET transponders, other approaches should be considered. In some cases, alternative approaches could effectively double the signal capacity that could be provided by a single narrow- or wide-band SPACENET transponder.

Encoding systems have been manufactured (Thomson-CSF, CBS) which time multiplex the odd and even fields of two synchronous video signals. At the receive end, the two "half-pictures" are digitized and each of the 262.5 lines of the half-picture is averaged with the next to produce an additional 262.5 lines to complement the transmitted information and produce 525-line video for each signal.

In addition to the above, a "time-frequency multiplexing" (TFM) technique has been developed[3] which may be used to transmit two high-quality NTSC signals in a 36-MHz transponder. Theoretically this would provide for the transmission of four good-quality signals in a wide C-Band or Ku-Band SPACENET transponder.

---

1 Rice, P. L. and Holmberg, N. R., "Cumulative Time Statistics of Surface-Point Rainfall Rates," IEEE Transactions on Communications, October, 1973.

2 Olsen, R. L., et al, "The aR^b Relation in the Calculation of Rain Attenuation, "IEEE Transactions on Propagation, March 1978.

3 Schmidt, R. L. and Haskell, B. G., "Transmission of Two NTSC Color Television Signals Over a Single Satellite Transponder via Time-Frequency Multiplexing," GLOBECOM 1982, November 30 - December 2, 1982.

APPENDIX

EQUATIONS USED IN THE ANALYSIS

The following equations were used in the examination of SPACENET transponders for single and multi-carrier FM/TV carrier applications:

1. Required earth station HPA power calculation.

2. Link performance equations.

   A. $(C/N)_u$
   B $(C/N)_d$
   C $(C/N)_t$
   D. $(S/N)_v$

REQUIRED EARTH STATION HPA POWER CALCULATION

The required earth station HPA power to satisfy specified operational performance may be determined from the following equation:

$$P_{HPA} = SFD_{s/c} - IBO + A_{iso} + L_s + L_a + L_{pt} - G_t + L_{tl} \quad (1)$$

where

P_{HPA} = the required HPA power, in dBW.

$SFD_{s/c}$ = the spacecraft saturation flux density, in dB/K.

IBO = the required transponder input backoff to maintain an intermodulation carrier-to-interference ratio between 20-25 dB:

IBO = 0 dB (for single-carrier narrow C-Band operation)

1 dB (for dual-carrier narrow C-Band operation), and

2 dB (for dual-carrier wide C-Band or Ku-Band operation)

A_{iso} = the effective area of an isotropic antenna aperture; -37.2 dB-m^2 @ 6.175 GHz and -44.5 dB-m^2 @ 14.25 GHz.

L_s = free-space loss in dB; a function of wavelength and earth station slant range to satellite (i.e., $L_s = 20 \log 4\pi R/\lambda$).

L_a = atmospheric absorption loss; 0.2 dB @ C-Band and 0.4 dB @ Ku-Band.

L_{pt} = pointing loss in dB; a function of frequency, satellite drift, and earth station diameter (0.5 dB assumed for both C- and Ku-Band).

G_t = earth station mainbeam gain in dBi

L_{tl} = transmission line loss between HPA and antenna feed input, in dB (3.0 dB assumed for both C- and Ku-Band).

LINK PERFORMANCE EQUATIONS

Uplink Carrier-to-Noise Ratio

The uplink carrier-to-noise ratio, $(C/N)_u$, may be expressed by the following equation:

$$(C/N)_u = SFD_{s/c} - IBO + A_{iso} + (G/T)_s - 10 \log k - 10 \log B - L_{ps} \quad (2)$$

where

$SFD_{s/c}$ = the spacecraft saturation flux density, in dB/K.

IBO = the required transponder input backoff to maintain an intermodulation carrier-to-interference ratio between 20-25 dB;

IBO = 0 dB (for single-carrier narrow C-Band operation),

1 dB (for dual-carrier narrow C-Band operation), and

2 dB (for dual-carrier wide C-Band or Ku-Band operation)

A_{iso} = the effective area of an isotropic antenna aperture in dB-m^2; A_{iso} = -37.2 dB-m^2 @ 6.175 GHz and -44.5 dB-m^2 @ 14.25 GHz

$(G/T)_s$ = the spacecraft receive system figure-of-merit, in dB/K

k = Boltzmann's constant, in j/K

B = transmission bandwidth (17.5 MHz for dual-carrier narrow C-Band operation; and 32.5 MHz for single-carrier narrow C-Band, dual-carrier wide C-Band, and dual-carrier Ku-Band applications).

L_{ps} = power-sharing loss (0 dB for single-carrier applications, 3 dB for dual-carrier applications).

Downlink Carrier-to-Noise Ratio

The downlink carrier-to-noise ratio, $(C/N)_d$, may be calculated from the following equation:

$$(C/N)_d = EIRP_{s/c} - OBO - L_s - L_a - L_{pt} + (G/T)es - 10 \log k - 10 \log B - L_{ps} \qquad (3)$$

where

$EIRP_{s/c}$ = the spacecraft saturated EIRP, in dBW.

OBO = the resultant transponder output backoff in dB, a function of the transponder input backoff (IBO); for a narrow C-Band IBO of 1 dB, OBO = 1 dB; for a wide C-Band or Ku-Band IBO of 2 dB, OBO = 1.5 dB.

L_s = free-space loss, in dB

L_a = atmospheric absorption, in dB (0.2 dB at C-Band and 0.4 dB at Ku-Band).

L_{pt} = pointing loss, in dB (0.5 dB assumed for C-Band and Ku-Band)

$(G/T)_{es}$ = earth station receive system figure-of-merit, in dB/K.

Carrier-to-Adjacent-Satellite Interference Ratio

The carrier-to-adjacent-satellite interference ratio, $(C/I)_{as}$, for a wanted satellite from a single adjacent-satellite, assuming a co-frequency, co-polarized, similar interfering signal may be calculated from the following equation:

$$(C/I)_{as} = [(SFD)_w - (SFD)_i + \Delta G_u] \oplus [EIRP_w - EIRP_i + \Delta G_d] \qquad (4)$$

where

SFD_w = the power flux density of the wanted signal, in dBW/m^2

SFD_i = the power flux density of the interfering signal, in dBW/m^2

ΔG_u = the off-axis discrimination of the uplink interfering earth station in the direction of the victim (wanted) satellite, in dB (calculation of this parameter is based on a 7-meter uplink interfering earth station at C-Band and a 5.5-meter uplink interfering earth station at Ku-Band; a 29-25 log θ antenna sidelobe pattern is assumed).

$\oplus$ = power summation calculation

$EIRP_W$ = EIRP of the wanted satellite; in dBW

$EIRP_i$ = EIRP of the interfering satellite, in dBW

ΔG_d = the off-axis discrimination of the wanted satellite downlink earth station, in dB (29-25 log θ antenna sidelobe pattern is assumed).

Link Carrier-to-Noise Ratio

The link, or total, carrier-to-noise ratio, $(C/N)_t$, is calculated from the following equation:

$$(C/N)_t = (C/N)_u \oplus (C/N)_d \oplus (C/I)_{as} \oplus (C/I)_{terr} \oplus (C/I)_{xpol} \oplus (C/I)_{im} \qquad (5)$$

where

$(C/I)_{as}$ = carrier-to-adjacent-satellite interference ratio, in dB

$(C/I)_{terr}$ = carrier-to-terrestrial interference, in dB (25 dB assumed at C-Band; not applicable for Ku-Band)

$(C/I)_{xpol}$ = carrier-to-cross-polarized channel interference ratio, in dB (26 dB assumed)

$(C/I)_{im}$ = carrier-to-intermodulation interference ratio, in dB (26 for dual-carrier narrow C-Band transponders; 22 dB for dual-carrier wide C-Band and Ku-Band transponders)

$\oplus$ = power summation, i.e., $(n/c)_t = (n/c)_u + (n/c)_d + (i/c)_{as} + (i/c)_{terr} + (i/c)_{xpol} + (i/c)_{im}$

Video Signal-to-Noise Ratio

The peak-to-peak luminance signal-to-noise ratio, $(S/N)_v$, may be expressed by the following equation:

$$(S/N)_v = (C/N)_t + 10 \log 3(f_d/f_m)^2 + 10 \log (B_{if}/2B_v) + W + CF \qquad (6)$$

where

f_d = peak composite video deviation, in MHz (6.7 MHz for dual-carrier narrow C-Band operation, 10.75 MHz for dual-carrier wide C-Band and Ku-Band applications)

f_m = highest baseband frequency, in MHz (4.2 MHz)

B_{if} = IF noise bandwidth, in MHz (32.5 or 17.5 MHz)

B_v = video noise bandwidth, in MHz (4.2 MHz)

W = emphasis plus weighting improvement factor (12.8 dB)

CF = rms to peak-to-peak luminance signal conversion factor (6.0 dB)

OFF-PREMISES ADDRESSABILITY, IDEAS TO APPLICATIONS

Larry J. Fox
Engineering Manager, Remote Addressable Systems

TEXSCAN CORPORATION
PHOENIX, ARIZONA

ABSTRACT

The "Idea" of off-premises addressability was introduced to the cable TV industry several years ago. Since that time, several manufacturers have undertaken the task of translating those ideas into the reality of off-premises addressable systems. Each has taken a somewhat different approach to the problem and the resulting systems are now entering the "application" stages. Production of system hardware has begun and systems are ready for installation on a practical basis. This paper presents a viewpoint on why and how the off-premises addressable systems were developed. The characteristics of the Texscan "TRACS" addressable converter system are described with discussion of how off-premises systems may be applied in present and future cable TV systems.

INTRODUCTION

A new generation of off-premises systems is presently being introduced on a practical basis in the CATV industry. The idea of off-premises addressability is not really new; in fact, off-premises addressability has been available in the form of addressable taps for some time. The new systems now finding their way into the marketplace are the product of natural evolution and growth resulting from similar evolution and growth in the CATV industry. It is appropriate to examine some of the factors which influenced (and continue to influence) the development and application of these systems as well as reviewing some of the important features of the various systems themselves.

EVOLUTION OF THE REQUIREMENT

First, it is important to remember that the basic objective of a CATV system is to provide quality communications services and make a reasonable return on investment while doing so. Although this may be a little oversimplified, it is still fair to examine any anticipated change in a system against this criteria. That is, does it provide better service or better profitability or both?

The advent of premium pay services provided a means of increasing revenues by offering a product which the customer perceived as more valuable. However, this resulted in a problem of controlling access to these services and managing frequent changes in levels of service without incurring significant customer service costs. Addressable systems evolved to meet this need. But the addition of addressability to the subscriber's set top converter added significantly to the cost of the equipment installed in the subscribers residence where it was out of the operator's control and subject to loss or tampering. The idea of off-premises addressability arose as a potential solution to this problem, providing the advantages of addressable control while avoiding the increased risk of loss.

THE SYSTEM EFFECTS

The effects of this evolution in systems can be seen by examining a model in each of the configurations of non-addressable, addressable and off-premises addressable systems.

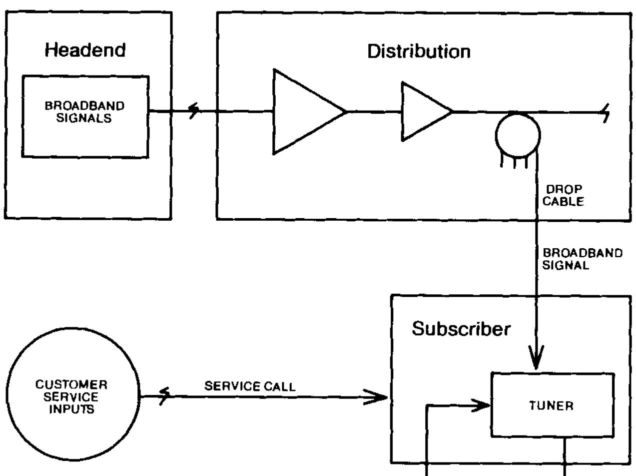
<u>Non-Addressable Systems</u> - In a non-addressable system, the headend provides the programming signals, the distribution system carries it to the subscriber's residence and the tuner (converter) allows the subscriber to select what he wants. The entire spectrum is available for his selection. Access control is exercised by external means (scrambling or traps) which may require comparatively minimual investment but larger operating expense due to continuing service requirements and theft of services and equipment. Figure One illustrates this configuration.

<u>Addressable Systems</u> - To implement addressability in this model it is necessary to add a control computer at the headend, a data communication path between the headend computer and the subscriber converters and add a control mechanism in the subscriber converter. Figure 2 illustrates this configuration. The changes in customer service level are entered into the headend control computer which interprets

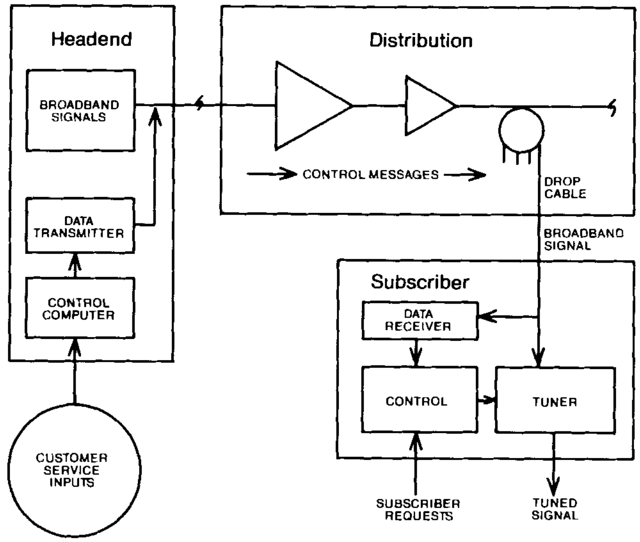
them into the specific messages necessary to update the converters and transmits through the data link in the cable to the set top converter where the control action is applied. More than likely this control action is applied in conjuction with some means of scrambling the controlled signals and what is actually being controlled by the headend computer messages is the de-scrambling device in the set top converter.

As noted previously, this system is still susceptible to theft of signals and the cost and complexity of the set top converter has increased. The valuable and vulnerable portion of the system is out of the operator's control in the subscriber's residence.

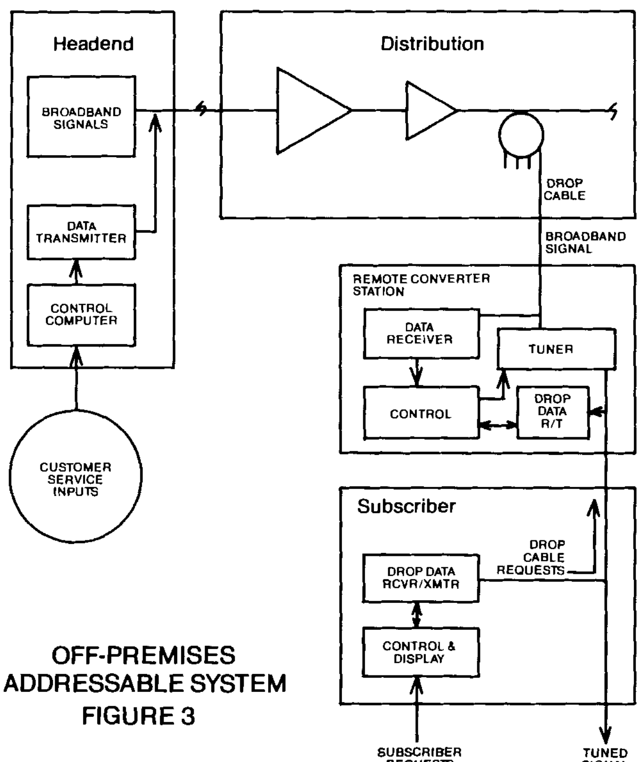
Off-Premises Addressability - To implement off-premises addressability in our model we must include the same elements necessary for the addressable system described above, but the location of the subscriber control element is changed. The headend computer and the customer service input are still in the headend. The data link is still required in the distribution system, but we have taken the set top converter functions and the associated control out of the subscriber's premises. In the place of the set top converter we add a control unit which allows the subscriber to request services. These requests for service are screened by the access control electronics and, if authorized, the service is tuned and provided to the subscriber. This configuration is shown in Figure 3.



NON-ADDRESSABLE SYSTEM
FIGURE 1



ADDRESSABLE SYSTEM
FIGURE 2



OFF-PREMISES
ADDRESSABLE SYSTEM
FIGURE 3

There are several advantages to this approach:

The broadband signal is not brought into the subscriber's premises so the subscriber no longer has access to any services except those permitted by the addressable system.

Scrambling of the premium signals is no longer necessary.

The control unit in the subscriber's premises can be made to be relatively inexpensive and even if stolen, cannot be used to steal signals.

The off-premises subscriber units may be grouped together to take advantage of sharing common resources such as the data communication receiver/transmitter and control microprocessor electronics.

Because the broadband spectrum is contained in the off-premises converter location, the level of ingress and egress of signals to and from the system may be reduced.

The primary disadvantage of this off-premises approach is that the environment where the control and tuning electronics is located is much more demanding than the set top environment. The off-premises units must be designed to operate and deliver services of acceptable quality over the full outdoor range of temperature, precipitation, vibration, electrical transients and RF level variation. Minimizing the size and power required by the off-premises equipment is important as is minimizing the cost of the in-residence components.

The in-residence set top control unit and the data link which allow it to communicate with the off-premises subscriber units are unique to the off-premises converter approach.

VARIATIONS IN APPROACH

The configuration of Figure 3 is characteristic of off-premises system which utilize the off-premises tuner approach. Some off-premises systems utilize slightly different approaches. The addressable tap and addressable trap systems, for instance, allow the tuner mechanism to remain in the home while the addressable control is exercised to allow or block access to certain pre-determined segments of bandwidth. Addressable jammers also operate on this principle except a jamming mechanism is turned on or off to obscure portions of bandwidth for a particular subscriber.

A variation of the off-premises tuner approach utilizes fiber optic methods rather than coaxial cable drops to carry the output of the tuner to the subscriber's premises.

IMPORTANCE OF "SYSTEM" EVALUATION

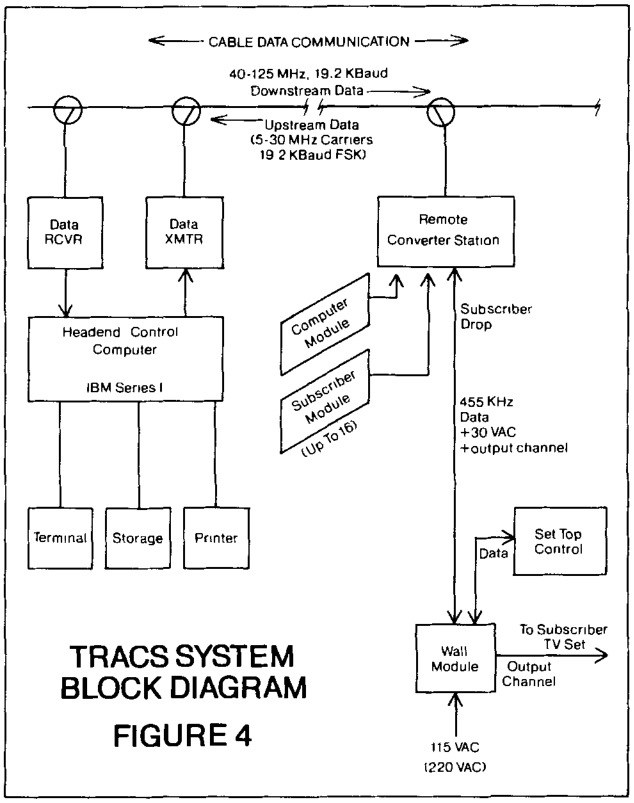
Previous papers have emphasized the importance of looking at the features of the complete system when evaluating an addressable system rather than taking a "Black Box" approach. This is true of off-premises addressable systems as well. The prospective buyer should throughly evaluate the available systems in light of his particular needs. A sampling of the applicable questions includes: Does the system provide operating software which will provide billing and business functions as well as control functions? Can the system easily be converted to two-way interactive operation? How versatile are the control features of the system? Does it depend on predefined tiers or can complete channel control be exercised? Will the system support pay-per-view? Will it support special event authorizations? Can security services be included? Can the command structure of the control system be expanded to provide more functions as services and systems grow? All these questions and many more should be carefully considered when considering a system for a particular application. Don't forget the basic rule: Quality service and reasonable profit.

OPERATION OF A REMOTE ADDRESSABLE CONVERTER SYSTEM

The Block Diagram of Figure 4 illustrates the configuration of a typical off-premises addressable converter system utilizing the Texscan Remote Addressable Converter System (TRACS). The headend control computer subsystem supports customer service funtions, billing, accounts receivable and general business functions as well as control and maintenance functions.

The remote converter stations are located throughout the distribution network to provide service to subscribers. Two types of remote converter station housings are available; a rack-mount unit designed primarily for indoor multi-dwelling applications and an cast aluminum housing designed for outdoor strand, pole or pedestal installations.

A computer module is located in each remote converter station to provide the control and communication functions. Each computer module can control up to 16 subscriber modules. The headend computer communicates with remote converter station computer modules via a one-way or two-way data link. (Conversion to two way is easily done by adding the appropriate RF modules.)



TRACS SYSTEM BLOCK DIAGRAM
FIGURE 4

Each subscriber module in the remote converter station includes a tuner assembly, a control microprocessor and the drop data communication unit. It is connected to the set top control in the subscriber's residence by the drop cable. Drop cable length may be quite long since it is no longer required to carry the entire broadband spectrum.

The drop cable terminates in the residence at the wall module. This module is a plug-in style transformer which provides an interconnection point for the various signals as well as providing power for the set top control. Optionally, it also provides power up the drop for the subscriber module. (115VAC line power, 60VAC cable power are optional powering methods for the indoor remote converter station; the computer module is cable powered in the outdoor remote converter station.)

The set top control is a small keyboard-display unit designed to be installed in the vicinity of the TV set. Favorite channel memory, special function data entry and parental control functions are provided. An infra-red remote transmitter is available. The subscriber enters his request for a channel in the set top control unit. This request is communicated back to the remote converter station and screened against the authorizations for that subscriber. If he is authorized for that channel, the tuner on his subscriber module is tuned to the requested channel. If he is not authorized for that channel, the tuner is tuned to a barker channel instead. This barker channel may provide a charcter generator display which informs the subscriber how he can sign up for the wonderful things carried on the service he has tried to access.

Two-way interactive capability is included in the TRACS system allowing up to three digits to be entered in a special function mode at the set top. The data is communicated back to the headend computer where it can be interpreted. This function can be used for opinion polling, games, pay-per-view impulse buying, etc. Also included in the system is the capability to add home security services.

Special event authorizations may be pre-authorized and strobed into effectivity by system wide command. All channels are authorized or not authorized by individual channels. Tiering is accomplished by software in the headend computer and may be retained in non-volatile memory on the computer modules so there is no loss of authorizations during power outages. If the headend computer system is not on-line for some reason, the remote converter stations and subscriber portions of the system will continue to function with the last authorization status.

A system-wide and individual force tune feature is included to support emergency alert and "Narrow-Cast" services. In two-way systems, status query commands are included to allow for collection of viewing status information (rating service). Individual privacy is protected in the software of the headend computer. The maintenance service features allow the operator to gather information on the operational status of the system down to the subscriber level to assist in trouble-shooting and maintaining the system.

The data communication formats have been designed to be flexible and many additional commands are available for later expansion of the system.

Up to 120 channels on two cables can be accomodated with A/B cable switching automatically performed. The specific tuning frequencies and channel ID's can be pre-programmed so that any combination of STD/HRC/IRC, A/B cable and offset can be provided. The FM band is provided on all subscriber modules if desired.

SUMMARY

Off-premises addressable systems can offer some very real advantages for the system operator. They are not totally without associated disadvantages, however, and we may reasonably expect that there will be some "Growth Pains" associated with them as this progression from idea to application continues. While this limited paper cannot be a complete coverage of the subject of off-premises addressability, it is hoped that the background presented here will provide some assistance to anyone considering the possibility of applying off-premises addressability in their systems.

ON THE USE OF FEEDFORWARD TECHNIQUES

Dan Pike

PRIME CABLE CORP.

ABSTRACT

Feedforward techniques as applied to system operation are discussed. Cost benefit data is given, with particular emphasis toward rebuild and bandwidth extension situations.

INTRODUCTION

The cable television industry has progressively required more linearization and bandwidth from its amplifiers. The concomitant channel loading describes some onerous requirements for distortion handling capability for both new build and system expansion applications.

The industry has crossed similar thresholds several times since its infancy, the most recent being just over a decade ago when the circuit architecture went from single ended to push-pull. We are at another such cross point where it is unlikely that dramatic transistor improvements will be achieved in the short term leaving that other circuit arrangements must be utilized that give the required improvements for today's loading.

Feedforward technology as applied to our present day CATV amplifiers will do that today. The purpose of this paper is to examine some case studies that will show how the application of this technology is relevant to the problems that a system operator faces today.

PREVIOUS FEEDFORWARD WORK

The development of a wideband CATV amplifier more linear than could be obtained with push-pull methods alone was described in 1976 by Prochazka and others.[1, 2] Early hypothetical work on the application of such an amplifier to the CATV operating economics was done by Henscheid and Birney in 1977.[3] Some of the first applications of hardware were recorded by Evans and Rhone[4] in 1979. The work by Henscheid and Birney has particular relevance to these case studies and correlates reasonably well.

CASE STUDY DESCRIPTION

The purpose of the studies was to examine the economics of feedforward linearization as applied to some given practical situations. It was also desired to examine the use of feedforward techniques to relieve dependence on coherent carrier techniques in dealing with composite triple beat distortion in extended bandwidth systems. Particular desire to maintain system transparency for services other than NTSC television[5] (such as high definition television) motivated the preference toward feedforward as opposed to coherent carrier techniques. In all cases except where specifically noted the use of HRC/IRC is not assumed or required. Its use would be optional, to achieve greater maintenance headroom.

The case studies presented represent sample designs done to aid decision making in daily practice. They were not necessarily chosen to be nationally or universally representative. The size of the sample ran from 10 to 40 miles, and included representative topography, exclusive of special or unusual areas. Cases 2 and 3 involve work done on the same area. Case 1 is a separate older study and is included to help identify historical trends.

While much data exists from these cases, only cost per mile data and certain relevant indicators are given; burdensome detail has been omitted. Readers are encouraged to structure similar cases around their existing circumstances for their own decision support.

CASE STUDIES

Case 1 involves construction of a 400 MHz system in a southwestern state considered in the summer of 1981 just as 400 MHz usage became popular. Amplifier linearity at that point was such that comparison from an all standard to an all feedforward case yielded a cost difference of about 12% for the total feedforward case. It is important to note here that IRC was mandatory in this case to meet composite triple beat (CTB) specifications. The amplifier specifications at that point were such that 400 MHz equipment could not be operated with the required distortion and noise parameters without unusually short cascades or unusually low distribution levels so as to be impractical.

This particular model was done over terrain which allowed the use of very long feeder lines without restrictions imposed by geography or mandatory trunk routing. The reduced actives count is tabulated and as a result of that reduced count the total power consumption was just about equal for the two cases. Other operating considerations were that the desired (transparent) specifications were met and exceeded without dependency on HRC/IRC techniques in the "B" case. A 450 MHz, 62 channel design today closely parallels these results.

Case 2 involved consideration of a new build in the late 1982 time frame with improved amplifier specifications to deal with, and the purpose of the case was to study the costs of one choice over another. Cases "A through D" are tabulated to show the relative cost impact for the active equipment for those four applications of feedforward technology. It is interesting to note here that in one case feedforward line extender application had a slight reducing effect on the costs for the total actives. It is necessary to point out that the model included optimization of the available technology to this particular system resulting in the choice of different gains of trunk station which reflects in the actives per mile count.

As in Case 1 the reduction in actives count made power draw virtually equal for the feedforward cases as for the standard case. Other operational considerations involve additional distortion headroom in the feedforward cases which could not be obtained without the use of coherent carrier techniques in the standard consideration. The reduction of actives count is also a significant operating consideration, though no attempt is made to quantify it.

This particular city is a typical eastern seaboard city with more than normal restrictions in routing and feeder line lengths and it is fair to say that all of the benefits of the longer feeder line that resulted from the use of feedforward could not be used in this layout, skewing this comparison slightly in favor of the conventional technology. It is more likely that a different topography would have yielded different results, probably more towards equal or lower costs in all feedforward comparisons to standard technology.

Case 3 involved a hypothetical bandwidth extension problem and is the heart of this discussion. There are all over the nation cable television systems operating with only a few years remaining on the present franchise, but a critical need for more bandwidth. This leads to a decision involving channel expansion techniques and their cost, which when added to the subscriber terminal costs, can exceed what may be possible to recover in the remaining franchise life. It is the purpose of this case discussion to point out that, subject to a few special considerations, it is possible to remain within the zone of good engineering practice and allocate the appropriate use of feedforward technology toward the problems that the average system operator will see in the next few years and that the application of this technology can achieve for the operator certain types of incremental bandwidth extension for proportional incremental costs. It should not be assumed that our discussion is to state a case whose technical and mechanical integrity is equal to new construction because always the desired long-term standpoint would be to reconstruct with new components, if it can be afforded. We will, however, see some acceptable compromise in this third case.

A few trends are worth examination as we consider this hypothetical case. First, almost all traditional systems, whatever their original cascade, have grown outward as the community has expanded and have approached cascade lengths of, say, 30 amplifiers. Any bandwidth extension or loading extension should consider a cascade of that depth. Second, the cost of active equipment has continued to slowly decline as a percentage of the total cost of plant construction leaving that any work that can be done with active changeouts yields the most efficient techniques for bandwidth and loading extension. Third, coaxial cables that have been manufactured within the last decade (particularly the gas injected types) are more predictable than their predecessors and, subject to an occasional malfunction of the manufacturing process, the performance of coaxial cable can be predicted and accurately projected for 50 to 100 MHz or more beyond its original frequency of use.

Empirical testing must be applied whenever this technique is considered this because certain channels may be rendered unusable because of periodic discontinuities in the cable affecting transmission in the extended bandwidth areas. The underlying assumption here is, of course, that the cable currently in existence is mechanically sound and not seriously flawed due to kinks, cracks, holes and all of the other ills of cable system operation. A separate discussion on the validity of the cable assumption is treated in Appendix 1.

Take, then, for assumption, a typical early 1970's system with an original upper bandwidth of 260 MHz, but a channel loading specification of 21 channels with a cascade of 20 trunks, 1 bridger and 2 line extenders. An operator with such a system who chose to expand the channel capacity might consider the following approach. We will assume, as previously stated, that the original cascade involving 20 trunk amplifiers has now gone to 30 and that the desired (best case) performance might be 400 MHz, 52 channels. Accordingly, as shown in 3(b), by using the existing trunk locations and feedforward technology available today in all the amplifiers by direct changeout, one might achieve that desired loading and bandwidth for an amplifier cost of about $3000.00 per mile, which correlates closely to the active costs in a new 400 MHz build. This assumes, of course, the existing cable is reused. The location of the line extenders is not necessarily considered to be the same as before. The required performance cannot be achieved with standard amplifiers.

Case 3(c) was drawn to demonstrate where the greater value of feedforward application really is, and as we would expect that value is in the higher level distribution plant amplifiers. Case 3(c) assumes the availability of a trunk amplifier with the necessary gain performance, but without assuming feedforward performance of that trunk amplifier and the summary shows that the required system performance can be met with only feedforward technology applied to the bridgers and line extenders. This yields about a 20% reduction in the total actives price, compared to 3(b).

The effect of this is substantial; it means that existing cable television systems can be fully modernized without disregard of good engineering practice. It means that cable television systems can be upgraded for costs that are more in line with what operators can realistically afford and facilitate rapid expansion in all of their plants and it means that the system architecture need not be radically changed to introduce multiple hubs, microwave, FM, multiple cable, or other transportation methodologies. There are, however, some considerations that must be taken into account such as the accumulation of inbound noise (and ingress) in a plant that was intended to be retrofitted for interactive operation, but there are adequate techniques to deal with those problems.

The opportunity for this type of incremental bandwidth extension and the opportunity to maximize the cost benefit from it rests with a larger than presently available family of equipment to be manufactured giving housing compatibility, especially in the distribution amplifiers. It is very likely that as a practical matter, an operator wouldn't push toward the full loading that has been shown in cases "B and C" from operation where only 21 channels had been possible before, but even a channel doubling for the costs that are suggested is quite a cost effective upgrade.

CONCLUSIONS

The purpose of this paper has been to show the following:

1. New designs with typical cascade depths at 450 MHz require the use of feedforward technology in order to be totally transparent.
2. Except with unusual system topography, the use of feedforward techniques is quite cost effective.
3. Operators faced with decisions on upgrading channel capacity but without the necessary time to recover investment on total rebuilds can particularly use feedforward technology to expand existing cable television systems to the requisite channel loading.
4. The techniques are most cost effective in distribution amplifiers.

ACKNOWLEDGEMENTS

Special thanks are extended to Richard L. Scott for the preparation of Cases 1 and 3. Thanks are also extended to Tom Polis and others at Communications Construction Group for the preparation of Case 2.

APPENDIX I

The cost effectivity of feedforward technology is discussed in the text. Minimizing the cost of bandwidth extension involves reuse of the existing cable and that issue is discussed separately here for purposes of clarification and support, since Case 3 assumed the use of existing cable.

As stated before the long-term consideration always favors reconstruction with new components, though when faced with the need for bandwidth extension without guarantee of adequate time to recover the investment, the shorter term consideration moves toward the use of existing cable without sacrificing sound technical principles.

Any mention of cable reuse usually spawns a veritable flood of concerns from the cable engineering community, and appropriately so, since it suggests the move towards uncertainty and technical risks. A survey of the relevant literature suggests that no theoretical limits await us for the types of extension this paper discusses so that our concerns are motivated by our experience and knowledge of the practical realities of cable manufacture and installation. Primarily, they deal with the uncertainty of structural return loss integrity of the cable at the extended frequencies.

Earlier experience with discontinuities in feeder lines was not always good,[6] as anyone that dealt with pressure taps can attest. Some early work (1968) by Lubars and Olszewski[7] characterizes the physical tolerances necessary for production of cables as bandwidth extensions to 300 MHz were achieved. Reasonable extrapolation from that work and comparison to then known manufacturing techniques shows an acceptable degree of risk for the extension techniques discussed in this paper. An internal publication of one of the cable manufacturers[8], again dealing with earlier bandwidth extension problems, treats the subject quite thoroughly. Defined are manufacturing perturbations that deal with dimensional variations of the inner conductor or outer conductor, variations in the dielectric between the two conductors, and off-centeredness of the inner conductor relative to the outer conducter. The effect of each on structural return loss is treated, and again, extrapolation of that data to today's case can lead one to responsibly believe that the risk is well worth taking as presented in the context of the paper. Private conversations[9] with leading cable manufacturing engineers confirm these assumptions. There are cases where certain empirical tests have been conducted on cables of the first generation gas injected era (and earlier) with results consistent with those assumed in this paper.

It is fundamental and mandatory to assume that any operator considering the bandwidth extension techniques using existing cables would do the necessary empirical testing involving amplitude sweep performance and perhaps time domain reflectometry performance so as to convince himself that the particular run of cable extant throughout his system is free of the manufacturing defects that could have yielded product suitable for use at the original frequency but no higher. These tests need not be burdensome; the standard time domain reflectometer has adequate sensitivity to diagnose discontinuities that might effect frequencies out to 400 MHz. Certainly, but not conclusively, amplitude sweep perturbations greater than those desired by the operator are indicative of structural return loss failures, though all three tests might be done to reduce the uncertainty. Once the cable is adequately characterized for the intended performance, an informed decision can be made about its usefulness and the desire to replace it.

It is important to point out that at the frequencies in question, in addition to the manufacturing process, construction irregularities can also play an important role, since a lashing machine could have easily introduced flaws at every revolution that begin to be visible in the 400 MHz vicinity. The characterization process will discover the unusable frequencies and allow responsible, informed decisions, that have major influence on project costs.

CASE STUDY SUMMARIES

	DESCRIPTION	COSTS PER MILE, ACTIVES (Relative)	[Actual]	ACTIVES PER MILE (Trunk)	[L. E.]	REMARKS
CASE 1						
Early 400 MHz New build, Southwestern states. 06/81	(a) All standard 20+1+2 cascade	(1.0)		(1.28)	[3.53]	(1,2)
	(b) All feedforward	(1.12)		(0.67)	[2.13]	
CASE 2						
Northeastern states New build 400 MHz 11/82	(a) All standard	(1.0)		(1.3)	[2.5]	(3,4,7)
	(b) Standard trunk feedforward line extenders	(0.98)		(1.1)	[1.9]	
	(c) Standard line extenders feed-forward trunk	(1.11)		(0.8)	[2.6]	(5)
	(d) All feedforward	(1.29)		(1.1)	[1.6]	(6,7)
CASE 3						
Expansion Model	(a) 260 MHz, 21 channel, 20+1+2 cascade	NA		(0.4)	[2.2]	(8)
	(b) 400 MHz, 52 channel loading, 30+1+2 cascade, all feed-forward	(1.0)	[3311]	(0.4)	[2.7]	(9,10, 11,12)
	(c) Assumed availability of 30 db gain, 400 MHz standard trunk module	(0.80)	[2651]	(0.4)	[2.7]	(13,14, 15)

REMARKS TO CASE STUDY SUMMARIES

(1) 53 db CTB, 43 db C/N
(2) IRC Mandatory to meet CTB specifications.
(3) 54 db CTB, 45 db C/N, all cases.
(4) 20+1+2 cascade, all cases.
(5) 30 db trunk spacing.
(6) 22 db trunk spacing.
(7) Feeder/trunk (standard) = 3.22/1
Feeder/trunk (feedforward) = 4.11/1
(8) Typical early 1970's system.
(9) Physical locations constant on trunk, variable on line extenders.
(10) Existing cable used.
(11) List price used.
(12) 30 db trunk spacing, 34 db gain line extender.
(13) Assumed cost of 10% above standard gain, and optimistic distortion performance that could, depending on hybrid and cascade performance, require paralleling techniques, but not feedforward techniques.
(14) 53 db CTB, 43 db C/N, all cases.
(15) Feeder/trunk = 6.6/1

REFERENCES

[1] A. Prochazka, P. Lancaster, R. Neumann, "Amplifier Linearization by Complementary Pre- or Post Distortion," IEEE Transactions on Cable Television, Vol CATV-1, pp 31-39, October 1976.

[2] A. Prochazka, R. Neumann, "Design of a Wideband Feedforward Distribution Amplifier," IEEE Transactions on Cable Television, Vol CATV-5, pp 72-79, April 1980.

[3] Bert Henscheid, Patrick J. Birney, "Design of a Wideband Feedforward Distribution Amplifier," IEEE Transactions on Cable Television, Vol CATV-5, pp 80-85, April 1980.

[4] William E. Evans, Jeffrey C. Rhone, "An Intercity Coaxial Cable Electronic Highway," IEEE Transactions on Cable Television, Vol CATV-4, pp 56-62, April 1979.

[5] Charles W. Rhodes, "An Evolutionary Approach to High Definition Television," Tomorrow's Television, SMPTE 16th Annual Television Conference,pp 186-197.

[6] Ken Simons, "Reducing the Effects of Reflection in CATV Feeders," Technical Handbook for CATV Systems, Third Edition, pp 57-63

[7] H. Lubars, J. A. Olszewski, "Analysis of Structural Return Loss in CATV Coaxial Cables," Wire and Cable Symposium, 1968, pp 1-21.

[8] Steve Fox, Comm/Scope Corporation, "An Analysis of the Parameters Which Cause Structural Return Loss in Coaxial Cables," pp 1-15, October 1973, Unpublished.

[9] Private Conversation, Brian Garrett, Comm/Scope Corporation, April 1983.

ONE-WAY DATA TRANSMISSION FOR CABLE APPLICATIONS

HEINZ W. WEGENER

WEGENER COMMUNICATIONS, INC.

ONE-WAY DATA TRANSMISSION FOR CABLE APPLICATIONS

ABSTRACT

The cable industry has created an extensive satellite connected point to multipoint communications system which is capable of supporting a large number of auxiliary services in addition to the primary video distribution. With the introduction of highly efficient audio subcarrier technology, new and innovative audio services for CATV are developing rapidly. Additionally, the auxiliary capacity is now starting to be exploited for distribution of data. With careful planning and utilization of spectrum efficient, cost effective subcarrier data transmission techniques, the existing cable video distribution system can deliver large amounts of data to provide many unique information services for cable subscribers and business applications.

This paper discusses applications and technical considerations for one-way data transmission using the CATV distribution network.

INTRODUCTION

The cable industry looks to data transmission as a future source of additional revenue. Many of the future applications involve two-way data transmission and a high degree of interactivity with the end user. Although this kind of data transmission is most conventional, there are some present limitations to many cable systems which prevents immediate implementation of this kind of data service.

Several examples of one-way data transmission in use today include the following:

- Improving the efficiency of the day-to-day operations of a cable system by streamlining and centralizing user authorization for premium services and pay-per-view events.
- Providing unique and innovative services to cable systems which help add subscribers and increase revenues.
- Localizing a nationally distributed video channel and allowing insertion of local advertisements.
- Electronic mail for distribution of hard copy system and program change information.

This paper discusses the use of video satellites as a data delivery system to the headend using data subcarriers and the vertical blanking interval and current cable applications using one-way data transmission.

TRUE ONE-WAY DATA TRANSMISSION

True one-way data transmission occurs if after data is transmitted there is no way to request retransmission if data has not been properly received. Data transmitted in this way is usually retransmitted on several occasions to guarantee "legible" transmission. This type of data transmission is best illustrated by teletext transmission.

QUASI ONE-WAY TRANSMISSION

Most one-way transmission of data has a feedback mechanism to indicate if the transmitted data has been properly received. For instance, in authorizing a customer to receive a premium service or a pay-per-view event, the customer indicates if data was not received by calling the CATV office and indicating that he has not received the requested service. Many one-way systems actually have this sort of feedback in one form or another. However, retransmission of a data stream usually requires a large data storage source. Determining if the transmitted data has been received is an important design consideration in elements that rely on one-way data transmission such as addressable set top converters.

CONTINUITY OF DATA SERVICE WITH ONE-WAY SATELLITE TRANSMISSION

BIT ERROR RATES

The satellite distribution network that feeds the cable industry is a very reliable communications network. This has been historically verified by the many radio networks and several data distribution networks currently using subcarriers above video channels to distribute their information. Also, the signal level fades for a satellite system tend to be very moderate and therefore the link parameters are predictable. Generally, an earth station that receives an excellent video signal will provide very good bit error rates (BER) (greater than 10^{-7} BER) using either subcarriers or the vertical blanking interval to transmit data.

IMPROVING THE BIT ERROR RATE

Forward error correction techniques are commonly used in data communications to improve error rates. However, to accomplish error correction, additional bits are inserted which reduces the actual throughput of the data stream. In a satellite transmission system, sometimes the same results of improved bit error rates can be achieved by increasing the deviation of the subcarrier on the main carrier or the bandwidth of the subcarriers used to transmit the data.

The use of forward error correction is fairly expensive and its use must be balanced against the reduction of transmission costs realized by being able to operate at lower uncorrected bit error rates.

HOW GOOD IS GOOD ENOUGH?

In determining the required performance of a data transmission system, a minimum acceptable bit error rate must be specified. The impact of data errors depends on if the incorrect bit occurred during a control byte or during a character byte. If the incorrect control byte is part of an address for instance, a large amount of data that follows and is intended for a specific location, could be lost. However, control and address bytes generally incorporate error correction bits for these bytes or theyare transmitted multiple times to prevent this. To help put into perspective what a certain BER means, Table 1 shows the time between bit error occurrances for different data rates and various bit error rates.

TABLE 1

TIME BETWEEN ERRORS

DATA RATE BITS/SEC.	TIME BETWEEN ERRORS FOR BER'S OF:		
	10^{-6} (Minutes)	10^{-8} (Hours)	10^{-10} (Days)
300	55.6	92.6	386.00
1200	13.9	23.1	96.5
4800	3.5	5.8	24.1
9600	1.7	2.9	12.1

For low data rates, it is impractical to conduct production tests to measure the higher bit error rates due to the time required to make the measurements. As the table shows, if as few as ten errors are accumulated to validate a bit error rate specification, the bit error rate tests can extend to many hours and days even for the higher data rates.

ERROR RATE VERSUS CARRIER TO NOISE RATIO

Figure 1 shows bit error rate as a function of carrier to noise ratio for a subcarrier FSK system. For data transmitted using the vertical blanking interval (VBI) there are many factors affecting the BER curve including the data level and the type of decoder used. For subcarrier data transmission, the deviation of the subcarrier on the main carrier can be adjusted to allow operation into different size earth stations while nothing can be done to significantly effect bit error rates of data transmitted in the VBI other than forward error correction once an optimum data level has been determined.

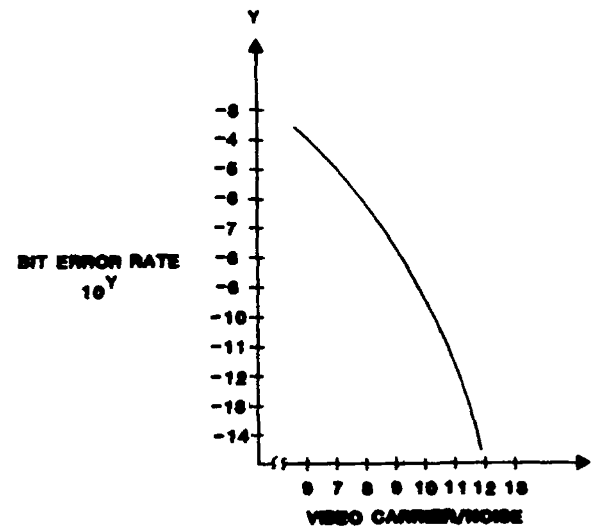


FIGURE 1.
BIT ERROR RATE VS VIDEO CARRIER/NOISE
FSK DATA SUBCARRIER

FACTORS THAT CAUSE BIT ERROR RATE DEGRADATIONS

EARTH STATION DESIGN

It is as important to have the proper amount of margin in an earth station for reception of data as it is for the reception of video or audio services. Many times the weakest link in the data transmission system is an antenna that is too small or a receiver that is not of commercial quality. Key performance parameters for receivers used for subcarrier or VBI data reception include adequate IF bandwidth and linear FM demodulators.

TERRESTRIAL INTERFERENCE

Interference due to terrestrial microwave is another major source of bit error rate degradation. If interference is present, IF traps used to eliminate terrestrial interference to improve video signals can severely degrade data transmission. The only acceptable solution to terrestrial interference is good planning and frequency coordination of the earth station prior to installation.

SUN OUTAGES

Sun outages result in a temporary loss of large amounts of data. It is important to recognize the occurrance of these outages and to avoid transmission of data to locations experiencing sun outages. Data can be transmitted at night to avoid sun outages. A more elaborate solution to sun outages is to transmit data simultaneously on two satellites and use alarm and switch-over circuitry to select the good channel.

WHAT HAPPENS WHEN ERRORS OCCUR

RANDOM ERRORS

Random errors are a result of thermal noise and generally cause only an occasional character in a data stream to be transmitted incorrectly. Simple error checking such as a parity error check can detect the bad character and not send it on. If the character does go through and it is not part of a control character, the total transmission is usually legible and the overall message of the transmission is not lost.

If the bad character is part of an address code, it is possible that a large amount of data destined for a certain location can be lost. However, most control characters are transmitted with error detection and correction coding or are transmitted multiple times and these errors are usually detected and corrected.

BURST ERRORS

Burst errors occur when many data bytes are lost all at once. This situation might occur during a heavy snow storm. The only feasible way of handling this situation is to detect the loss of data and request a retransmission of the data.

Generally the consequences of data errors are not catastrophic because the equipment using the data generally employ extensive error checking circuitry that prevents bad data from proceeding further downstream.

SOME WAYS OF TRANSMITTING ONE-WAY DATA OVER THE SATELLITE TO THE HEADEND

The following paragraphs discuss ways of transmitting data over the satellite using existing video channels and using either subcarriers or the vertical blanking interval to transmit data.

AUDIO CHANNEL WITH PHONE MODEMS

State of the art subcarrier technology such as the Wegener 1600 System allows placing high quality 3.4 kHz voice channels on 30 to 45 kHz spacing in the baseband above video. With these channels, a conventional phone line modem can be used to send the data over the satellite. The audio characteristics of this 3.4 kHz satellite channel are far superior to a conventional phone line, and should provide extremely transparent data transmission. Phone line modems, however, are quite expensive for higher data rates since they must transmit data reliably through somewhat unpredictable and varying quality transmission channels. Also, most phone line modems have full duplex capabilities and other features which are not necessary in one-way data transmission. Table 2 shows the range of the prices for some phone line modems. Following are trade-offs of using this system.

Advantages

- System can be connected directly to local phone lines at the cable headend for further distribution of the data.
- High degree of noise immunity inherent in this system.

Disadvantages

- Not a spectrum efficient approach for lower data rates.
- Very expensive at higher data rates.

TABLE 2

PHONE LINE MODEM PRICE RANGES

DATA RATE (BITS/SEC.)	APPROXIMATE PRICE RANGES ($)
300	130 - 400
1200	250 - 1000
4800	1500 - 4000
9600	3000 - 7000

AUDIO FSK

Expanding slightly on the phone line modem concept of using audio FSK carriers, this technique also uses audio channels but of higher bandwidth and quality to transmit higher data rates using simple FSK modulation schemes. This eliminates the expensive part of a high data rate phone line modem since this modem must get those data rates through a 3 kHz voice channel. In the satellite application, the higher data rates can be transmitted over higher frequency audio channels which are readily available. Using this technique, a 9600 Baud data demodulator designed for satellite applications costs about one tenth what a 9600 Baud phone line modem costs. Following are some trade-offs of this system.

Advantages

- Has a high degree of noise immunity.
- Very cost effective.

Disadvantages

- Not optimally spectrum efficient.

SUBCARRIER FSK

This technique directly modulates the subcarriers and provides a much higher spectrum efficiency than the audio FSK technique. Other modulation schemes besides FSK could be used.

Advantages

- Is much more spectrum efficient, (1 bit/Hz).
- Cost effective.
- Capable of high data rates.
- Large data throughput available using the spectrum above video.

Disadvantages

- Lower data rates require use of demultiplexers which adds expense.

VERTICAL BLANKING INTERVAL TRANSMISSION

This technique either uses convention teletext protocols or uses the vertical blanking interval lines simply as a data transmission path for standard RS232C asynchronous data channels. For RS232C transmission, incomming data is stored and then burst out on a video line in groups of thirty or more bytes at a time. Figure 2 shows the Wegener Series 2100 VIDATA® used for VBI transmission of data. Following are some trade-offs of this technique.

Advantages

- The data stays with the video signal.
- This is a cost effective home-data delivery system for text (KEYFAX for instance) with the availability of low cost home decoders.

Disadvantages

- This technique relies heavily on a good video transmission link.
- The optimum data levels for satellite and cable transmission are different.
- There is a limited data throughput (maximum of about 9600 Baud per line per field).

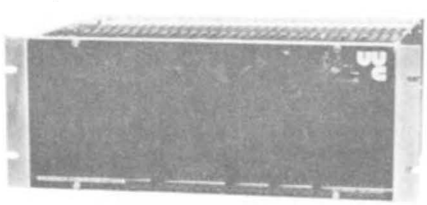


FIGURE 2
Series 2100 Asynchronous Data Transmission System

SOME CURRENT APPLICATIONS OF ONE-WAY DATA TRANSMISSION

TELE-COMMUNICATIONS, INC. - (TCI) - SATELLITE ADDRESSABLE SYSTEM

This system announced by TCI in April of 1983 allows TCI to authorize premium services and pay-per-view events for customers in their systems located throughout the United States from a central computer located near Denver. A subscriber calls the computer center and requests either to add or delete a premium service or to receive a pay-per-view event. The authorization to the set top converters is then sent first over an SCPC channel to the Group W uplink in Stamford, Connecticut where it is placed on a data subcarrier in the Satellite News Channel (SNC) baseband using equipment manufactured by Wegener Communications. This data channel is sent to all headends, demodulated by a Wegener subcarrier data demodulator, processed by equipment manufactured by Jerrold, and sent to the subscriber using a data carrier at 106.5 MHz using an FM modulator also manufactured by Wegener Communications.

ELECTRONIC PROGRAM GUIDE

This service offered by United Video provides cable systems with localized CATV program guides which are assembled by a computer center located in Tulsa, Oklahoma. Programming information on premium channels and network stations are automatically updated on a daily basis and the individual system receiving the service can call in local schedule updates to the computer center in Tulsa. This information is then formatted and sent out on a 2400 Baud data channel over a phone line to the United Video uplink near Chicago, Illinois. The data is then placed on a 2400 Baud data subcarrier using equipment manufactured by Wegener Communications where it is then made available to all systems receiving the service. Imbedded in the data is an address code which indicates who is authorized to receive the data at the headend. The data is demodulated by a subcarrier data demodulator manufactured by Wegener Communications and when a transmitted address code is matched with the local code, is loaded into a character generator which has sufficient memory to store several days of programming information. This information is then sequentially put on the screen under control of the character generator.

CABLE NEWS NETWORK (CNN) PRINTER CHANNEL

Although at the time of this paper, this service was not specifically used for CATV applications, this technique may be used in the future for affiliate updating and news distribution. The system that CNN is using provides program queing and timing information to radio and television affiliates receiving CNN Headline News.

The information for this service originates from a computer located in the Turner Programming Services facilities in Atlanta. Data is transferred from the computer to one or more of the eight 300 Baud data channels at RS232C levels. The individual channels are then multiplexed into one 3000 Baud data stream which is then modulated on a data subcarrier using a system developed and manufactured by Wegener Communications. At the receive locations, the data is demodulated and demultiplexed and affiliates can select any four of eight data channels to drive one or more printers. The entire receive package is manufactured by Wegener Communications and provides a highly reliable and flexible way of distributing hard copy information to all affiliates.

CABLETEXT

Since 1980, Southern Satellite has distributed news and other information services to cable headends using the vertical blanking interval as the data transmission medium. The information from the news services passes through a computer where the data is formatted for distribution over the satellite. This information is placed in the vertical blanking interval by insertion equipment manufactured by Wegener Communications. The data is transmitted in burst format to all cable systems where it is converted to an RS232C data stream by decoders placed at the headend.

THE WEATHER CHANNEL

Another example of one-way transmission using the vertical blanking interval is the Weather Channel. Data that provides local forecast information is transmitted from a computer to insertion equipment manufactured by Wegener Communications where it is placed in the vertical blanking interval of the Weather Channel video signal. This data goes to affiliates and provides the current weather forcast for that area. The information is downloaded into a character generator, (located at each headend) that has sufficient memory to store the current forecast. Local weather sensors are provided that input local conditions to the character generator for display on the TV screen. In addition, a keyboard is provided to the CATV operator to allow him to insert local commercials. All of the downloaded data which provides the localized information is inserted in the real time video on command of data signals generated at the Weather Channel control center in Atlanta, Georgia.

THE FUTURE

The above shows some very innovative ways that one-way data transmission is currently being used in CATV applications. The future will bring additional applications that can both improve the efficiency of the operations of a CATV system and also generate new revenue from specialized data services. The development of highly efficient and cost effective subcarrier data equipment is making many data services economically feasible for cable systems today.

PRACTICAL ASPECTS OF HOME TELETEXT

GARY W. STANTON

SOUTHERN SATELLITE SYSTEMS, INC.
TULSA, OKLAHOMA 74136

ABSTRACT

There have been many learned papers describing the detailed technical aspects of teletext transmission; most in language only understood by others with an intimate knowledge of the subject. This paper defines the requirements for the practical implementation of home teletext reception in the cable television environment.

Since data integrity is the measure of technical success, the items which effect data integrity are deliniated. Included are the satellite path, receive earth station, satellite receiver, cable modulators, AML link, and the cable plant itself. Results of various measurements and observations describing the effect of each subsystem have been made and the results will be described. Practical suggestions for achieving desired results in the most critical areas are presented.

INTRODUCTION

The first vertical interval transmission to the cable television industry was conducted at the NCTA Convention in Las Vegas in 1979. This demonstration, although only partially successfull, showed that data could be transmitted on the vertical blanking interval on a satellite signal. Since that date, knowledge has been obtained on the various parameters that affect successfull vertical blanking interval transmission to and through the cable environment.

During the last four years knowledge has been gained, various standards have evolved, equipment has been designed and services implemented using vertical blanking interval technology. Numerous degradation factors peculiar to satellite television transmission and to the cable environment have been identified. To offset these factors, error correcting techniques have been developed which give several orders of magnitude improvement in data integrity. With these improvements, home teletext is suitable not only for video display, but also for electronic mail and downloading of computer software and games.

HISTORY

It is generally acknowledged that the first commercial use of vertical blanking interval technology was by the British Broadcasting Company in Great Britain. The BBC Ceefax system which was designed specifically for the 625 line PAL television system in use in Great

Britain was not usable in the United States without significant change.

Two of the most significant differences are data rate and screen format. The 625 line system utilizes a data rate of 6.9375 Mbits/sec. which is faster than can be used in the NTSC system. The second difference is screen format. In the Ceefax system there is a fixed relation between the data byte's position in the transmit line and its position on the video display. In Great Britain, forty usable data bytes are transmitted on each vertical blanking interval line which correspond to a video screen format of forty character width. Depending on data rate, only 36 or 37 usable bytes can be transmitted in the NTSC system. In order to use a version of the Ceefax system in the United States these two parameters needed to be modified to fit the NTSC system. The basic incentive for using the Ceefax system is the availibility of LSI chips from several sources which make teletext decoders reliable and economically practical.

At the NCTA Convention in 1979, Southern Satellite Systems displayed a primitive implementation with a data rate of approximately 3.2 Mbits/sec using two vertical blanking interval lines for one display line. By late 1980 a data rate of 5.554 Mbits/sec was in use and the screen was formated with a 40 character by twenty row display. The mapping technique used was formulated by Mullard Labs.[1] In early 1983, the data rate was increased to 5.7272 Mbits/sec to be compatible with the proposed broadcast standard. At the same time, the video screen format was improved to allow the display of 24 rows of text instead of 20 rows.

CUSTOMER SERVICES

The initial services provided were the delivery of two news services to cable television headends. The equipment utilized was a video-in/video-out commercial quality teletext receiver. It was packaged in a rack mount chassis and specifically designed for direct interface to a satellite receiver. At this point in time, only problems inherent in satellite transmission and satellite receivers had been addressed.

Shortly thereafter a teletext transmission format was developed and a receiver designed featuring a data output rather than the video output. The initial purpose was to provide an interface between the vertical blanking interval and a character generator at a cable television headend. This provided the operator the opportunity to use his sophisticated character generator for both a national alphanumeric news channel and for local generated text or weather information. As is the case with the video output unit, the data output unit was packaged in a rack mount chassis with an interface specifically designed to interface with a satellite receiver. As may be noted, both of these units were designed for installation at a cable television headend or other commercial location where a baseband video signal was available.

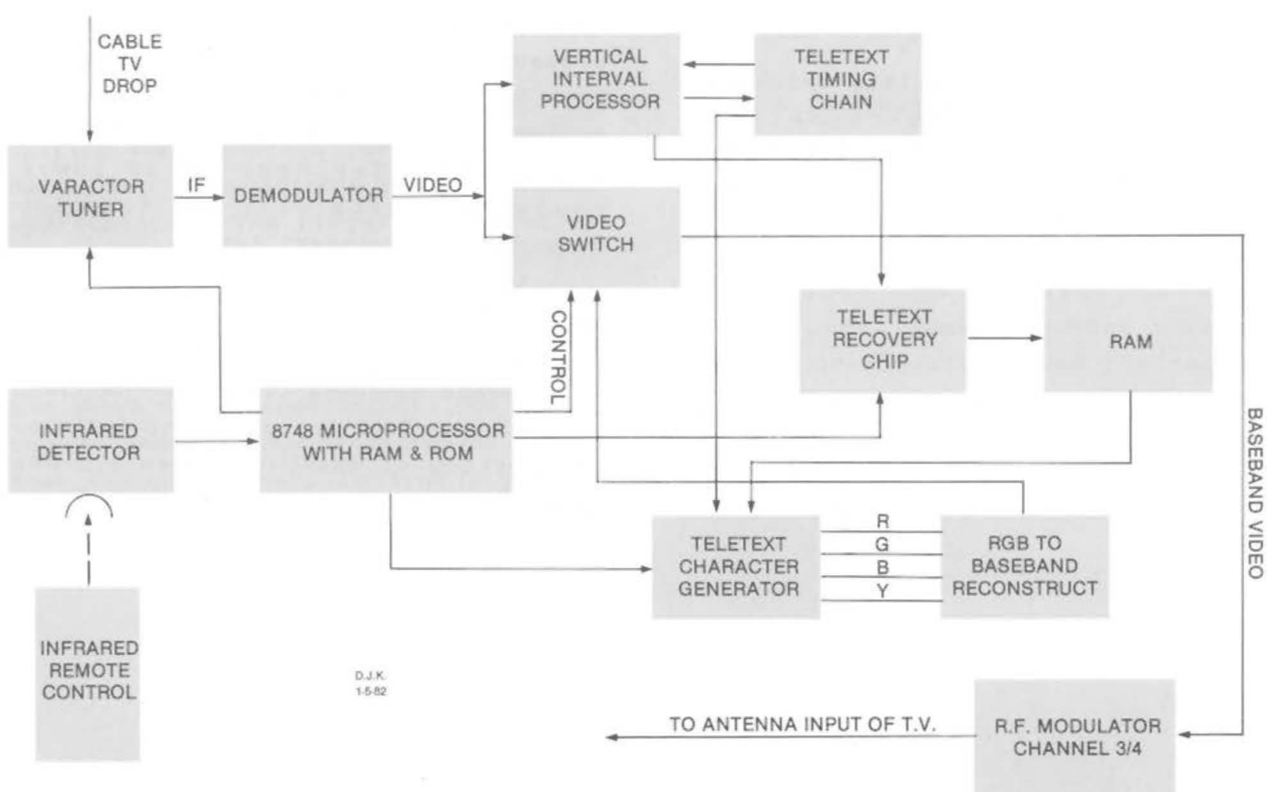
HOME TELETEXT

Recently Southern Satellite Systems has introduced Keyfax, a home teletext service. This service utilizes the United States proposed version of the BBC Ceefax standard which was proposed to the Federal Communications Commission.[2] The service features over one hundred video pages of text from which the viewer can select. This service is presently being transmitted on the vertical blanking interval of WTBS which is on SATCOM IIIR Transponder 6.

To implement this service, a set-top teletext decoder was necessary. The unit designed features a full cable television converter with infrared remote control and a built in teletext decoder. This unit can be used to replace existing converters in non-scrambled systems or as an add on unit where scrambling is used. A block diagram is shown in Figure 1.

As a companion to the above teletext decoder which has a typical Channel 3 or 4 output, a similar unit is being designed which has a standard RS232C data interface. This will be ideal for downloading information to printers and home computers. Its addressable funtion will allow specific users to get only the data to which they subscribe.

The data interface unit, combined with vertical blanking interval technology offers the ability to deliver one way data from a central point to thousands of locations simultaneously. This feature is particularly useful to the news services, commodity services, and financial information industries. It is presently being used by customers in these industries to deliver information to cable television headends and to home subscribers.



THE CABLE TELEVISION SYSTEM

There are numerous factors in the cable environment that effect teletext performance. At the headend, the earth station, satellite receiver, and the cable modulator all affect performance. In the cable plant, the AML microwave, the amplifiers, and the drops can also affect performance. Each item will be discussed separately.

1. Receive Earth Station

The quality of data received is directly proportional to the signal to noise performance of the receive earth station. A typical 3.6 meter with a 100 degree LNA in the central United States produced an error performance of 1 error in 10^6 bits transmitted. For some data applications this error rate may not be adequate. A larger receive dish would be necessary to lessen the number of bit errors. A 4.5 meter dish appears suitable for most applications.

2. Satellite Receivers

The quality of the satellite receiver can have a major effect on the performance of the teletext system. Of extreme importance is the IF bandwidth of the receiver. Tests indicate that a bandwidth of 30 mHz or greater is required for successful teletext operation. Some of the home quality receivers have an IF bandwidth of 25 mHz or lower; usually to improve apparant video threshold. The lower bandwidth will distort the data by limiting the frequency response of the system. This limiting will severely round the data pulses and cause both positive and negative overshoots in the data area. In one extreme case, the negative data overshoot exceeded 20 IRE units with the result being the television receiver's sync circuitry became erratic.

The test instrument required to measure and observe this effect is a full function waveform monitor, such as a Tektronics 1480. Alternately, a 50 mHz oscilloscope can be use if it features a television sync horizontal trigger.

For most purposes, most commercial quality satellite receivers that have been used in the cable industry over the last five years meet the 30 mHz requirement. However, due to cost pressure, several major manufacturers have been considering lower bandwidth products to be competitive with the home satellite offerings. These lower bandwidth units will not function properly on a teletext system.

A second effect inherent in the satellite receiver is video filtering. It is common practice today to incorporate bandpass filter on the video output which limits the band to 4.2 mHz. The portion of the band above 4.2 mHz contains the aural carrier at 6.8 mHz and most often numerous other subcarriers and/or noise. All receivers are equipped with either a 6.8 mHz notch filter or the low pass filter. However, those older receivers with only a 6.8 mHz filter will pass the energy of the additional subcarriers which will manifest itself as video noise. If an older receiver is to be used, an external low pass filter is recommended if the teletext decoding is to be accomplished at the cable television headend. For decoding on a cable system, the filter is not required as the modulator will provide the filtering.

3. Terrestrial Interference

One of the common problems that plauge many receive locations is interference from terrestrial microwave sources. Unless the interference is obnoxiously bad, it is frequently ignored. Unfortunately, with teletext it cannot be ingnored as it produces the same effect as if the system was operating at threshold. The best solution is shielding the receive dish from the interfering signal.

If shielding is not possible, filters are commercially available that have produced acceptable results in many applications. The filter is placed in the IF of the receiver and is either a 60 mHz or a 80 mHz center frequency filter, depending on whether the offending carrier is 10 mHz below or 10 mHz above the desired signal. The filter chosen needs to be optimized to remove just enough of the offending signal to provide optimum data reception. A filter with too deep a notch will cause as much degredation as no filter at all.

4. Modulators

The cable television modulator can damage the vertical blanking interval data. Fortunately, it is the adjustment of the modulator that is most often the problem, rather than the modulator itself. Of particular importance is preventing video overmodulation as well as maintaining the aural level at -15 to -19 db with respect to the main carrier. It is equally important to correctly maintain the aural level on the next adjacent lower carrier.

Modulators that do not have bandpass filters can allow harmonics to pass into the system. This is typical of the strip amp variety used in some older cable systems and most frequently used in apartment buildings, hotels, and other institutional systems. This type of installation frequently can be improved by adding filters or replacing the modulator being used for the channel carrying teletext.

5. Microwave Radio Systems

There have been no reported problems with FM microwave systems. The investigation of one reported problem with an AML system indicated the system was badly out of manufacturers tolerences. Numerous other operators have successfully passed the vertical blanking interval data over AML microwave systems. It can be concluded that a properly operating AML system will not affect teletext data.

6. The Cable Plant

A properly adjusted cable plant will correctly pass the vertical blanking interval. Typical problem areas are malfunctioning AGC amplifiers, DC power supplies with high AC ripple, and leaks in the cable system. The leakage is extremely significant for on-channel operation of off air signals with teletext. The leakage generates the same effect as multipath reflections, except the weaker signal is before the desired signal rather than after it. In some systems, channels 18 and 19 (E and F) are susceptible to two-way radio interference. This interference will destroy the integrity of teletext data.

A third cable plant problem is that of poor drops. This may be due to inadequate levels: teletext reliability is enhanced with a strong drop signal, typically between 5 and 10 dbmv. Installations subjected to high levels of RFI may also be unreliable.

It has been observed in conventional cable plants that certain channels are cleaner than others. This is generally a function of the many combinations that result from the addition and subtraction of the carriers and their harmonics. A spectrum analyzer is generally required to track this phenomena, however changing to a different channel is often easier and may solve the problem.

7. Test Equipment

The equipment used to test a cable plant can have an adverse effect on teletext performance. Of particular importance is the high level sweep equipment used on many systems. This type of sweep equipment will completely destroy teletext integrity. The newer low level sweep techniques can coexist with teletext data, however some degradation has been observed.

8. System Maintenance

It has been observed that proper maintenance and adjustment of the system is critical if low error rates are expected. Of critical importance is maintaining the proper levels between satellite receiver and modulator, and the correct modulation levels for both the video and aural level of all channels. It is common to find improper levels due to either misadjustment or subsequent unterminated or double terminated equipment. Care in headend setup and maintenance is mandatory for success in teletext transmission.

ERROR PERFORMANCE AND IMPROVEMENTS

Several techniques have been developed to improve the data integrity. The basic code structure provides for parity checks on all data bytes. The address codes are further protected by Hamming codes. This is a code where a single bit error in a byte will be corrected and a double error will be corrected. These methods are in current use.

For certain data a method of multiple transmission has been developed. For the video type of teletext unit, the second transmission overwrites the original transmission; however if a parity error is detected in any given byte, the byte from the first transmission is left on the display. This technique gave a significant improvement in data integrity and is used for critical transmissions.

The same technique has been used for the data output teletext unit. A control code is transmitted which tells the decoder whether it is receiving the first or second transmission of the identical data. Test have shown that this technique generates 100 times improvement in data integrity.

Another technique usable on the data output type decoders is that of longitudinal parity check or LPC. In this technique, a byte is transmitted at the end of each vertical blanking interval line which is the result of calculating parity on a bit by bit basis. From the LPC byte a single byte error can be corrected in any given vertical blanking interval line. The improvement is almost as good as the multiple transmission method when basic error rates of less than 1 x 106 exist. This improvement diminishes for worse error rates and improves at better error rates. Of significant importance is the added overhead is only 3% rather than the 2:1 overhead in the multiple transmission technique.

CONCLUSIONS

The use of the vertical blanking interval for delivery of information to the cable television headend and to the homeowner is now feasible and practical. Reliable equipment is available at reasonable costs. A well maintained cable system will be able to pass the vertical blanking interval information successfully. Small changes in other systems may be required, most often in the maintenance practices.

REFERENCES

1. G. O. Crowther, TELETEXT AND VIEWDATA SYSTEMS AND THEIR POSSIBLE EXTENSION TO EUROPE AND USA, IEEE Transactions on Consumer Electronics, July 1979 Volume CE-25 Number 3.

2. United Kingdom Teletext Industry Group Petition for Rulemaking before the Federal Communications Commission, March 26, 1981.

RELIABLE POWER FOR CATV SYSTEMS

Robert J. Plow

LORAIN PRODUCTS

The trend to greater interactive use of today's cable systems requires power sources of greater reliability than the AC utility power line. The head end, outside plant, and subscriber each present unique power requirements to the system designer. The causes and effects of power line problems are defined and the various equipment choices to protect critical equipment at each location are analyzed.

The Need for Reliable Power

The capabilities of Cable TV are expanding every day. The systems are rapidly changing from an entertainment television distribution system to a true communications network. The bandwidth available on a cable system today allows the handling of data transmission, security information, and even telephone conversations in addition to the traditional television signals.

As the uses expand beyond entertainment services, the need for reliable system operation also increases. A key element in the system reliability is the power source for the various requirements.

Electrical power is required at three distinctly different locations within the cable system:

1. Head End
2. Outside (Trunk/Line Amplifiers)
3. Subscriber

The traditional source for power at each of these locations has been the commercial AC power line. Utilizing the power line directly offers three advantages:

1. In the United States today, commercial AC line power is readily available.
2. Utilizing the commercial line is inexpensive. Power conversion equipment cost is the lowest of any methods to be discussed.
3. The commercial AC line in the United States is generally reliable enough for most applications.

The commercial power line, however, offers certain disadvantages to today's interactive and expanded capacity cable systems.

Four potential problems with using the AC line are described below with the possible causes for each problem.

1. Blackout--A blackout is a complete loss of AC power and can last from a few seconds to many hours.
2. Interrupt--An interrupt is a momentary loss of power lasting from a portion of a cycle to several cycles.

   Interrupts can be caused by the utility company's switching of transmission lines, automatic closing circuit breaker operation, or switching to or from an on site engine-alternator under actual or test conditions.
3. Brownout--A brownout is a long lasting reduction of AC voltage.

   The reduction can be to a level that causes marginal operation of connected equipment.

   Brownouts are caused by the electric utility company intentionally reducing the voltage to reduce the load on generating units or by continuous overloads on the distribution systems.

4. Transients--Transients are momentary voltage excursions--either high or low. They may be of very short duration (millionths of a second) or of long duration (several seconds). A low voltage condition lasting from one cycle to several cycles could be called a dip while a high voltage condition could be called a surge.

   Transients can be caused by lightning strikes, switching of power factor correction capacitors, large load changes, or faults on other circuits in the same distribution system.

Each load connected to an AC power system should be investigated as to its response to each of these problems.

Each location in the cable system (head end, amplifier, and subscriber) may have different needs for power.

The Head End

The head end will have the highest power demand of any place in the system and may have the most critical power requirements due to the complexity and sophistication of the installed equipment.

Computers are most sensitive to power line anomolies and will often shut down for no apparent reason, yet the power line is often the culprit. The effects of a blackout are readily noticeable by operating personnel. An interrupt may appear as nothing more than a blink of the lights, but this is sufficient to shut down a sensitive computer. Transients are not noticed by operating personnel but may actually damage sensitive electronic components immediately or cause a degradation in a component which leads to failure at a later time.

The system designer should consider each piece of equipment installed at the head end individually and ask the following questions regarding that equipment's operation following a power line problem:

1. What effect does the loss of this equipment have on operating revenues?
2. What effect does the loss of this piece of equipment have on the safety of subscribers or operating personnel?
3. What is the cost to restore the unit to operation, such as reprogramming time?
4. What are the effects of subscriber complaints upon loss of that particular service?

The designer must then decide which pieces of equipment will need protection and the degree of protection to be provided.

The power line problems that are solved the easiest and most economically are brownouts and transients. Both problems can be protected against by simply employing a line voltage regulator; however, the regulator will offer no protection against blackouts or interrupts.

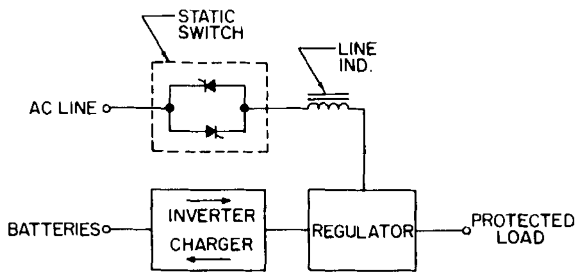
The simplest line voltage regulator is a ferroresonant transformer. Its energy consumption is low and the initial purchase and installation price are the lowest of any of the alternatives to solving power line problems.

The next highest level of protection is an engine alternator. The engine alternator by itself will offer protection against blackouts and brownouts but does nothing for transients or interrupts. A line voltage regulator would have to be used to protect against transients. The installed cost of an engine alternator is approximately 3 to 3½ times the cost of a line voltage regulator and the cost of the regulator would have to be added to it to offer protection against the three most common types of AC line problems--blackout, brownout and transient.

The combination of a line voltage regulator and an engine alternator still offers no protection against an interrupt in AC line voltage which may still cause problems with computer operated equipment. A time delay of many seconds to several minutes may be encountered as the engine alternator cranks, starts, and comes up to speed. Another interrupt will be experienced when the transfer switch reconnects the critical load to the commercial line following the use, during actual or test conditions, of the engine alternator.

Protecting the critical loads against the possibility of a power line interrupt requires the use of an energy storage device that can provide the energy immediately--unlike the start up time required in an engine alternator. The most common type of energy storage device available for this purpose is the lead-acid battery; however, the energy stored by the battery is not directly usable by most computer operated equipment; thus, the battery power must be converted by means of an inverter into usable AC power.

One type of Uninterruptible Power System (UPS) that can protect against all forms of power line problems--blackout, brownout, transients and interrupts--is depicted in the drawing below.



The heart of the system is the regulator which is a line voltage regulator that both regulates the line voltage for brownout protection and filters the line voltage for transient protection. A battery is provided as the energy storage device. A continuously operating inverter connected to the battery is also connected to the AC line regulator. If the line voltage should become unacceptable as a source of power for the regulator, the line is simply disconnected from the regulator by the static disconnect switch and the inverter, which has been running, simply supplies power to the regulator from the battery.

When the AC line voltage returns to normal limits, the control circuits will bring the inverter in step, or phase, with the AC line and reconnect the regulator to the line voltage. The control circuits then go one step further and allow the inverter to run slightly out of step, or at a different phase angle, with the AC line and draw a small amount of power from the regulator and feed it back to the battery to recharge it. Thus, the inverter is forced to "run backwards" to become a battery charger.

The installed cost of a UPS less the battery bank may be 1 to 1½ times in installed cost of the engine alternator. Adding a battery bank sufficient to operate a UPS at its full rated load for two hours can make the installed cost of the UPS and the battery approximately 2 to 2½ times the cost of an engine alternator.

Engine alternators are often installed of a size large enough to handle the complete requirements of the head end including the critical head end television processing equipment, computers, air conditioning, and lights. It is generally uneconomical to install a UPS large enough to handle all of these loads. The system designer should segregate those loads which are truly critical to the operation of the systems and operate only the critical loads from the UPS. It would not be unusual to have head end with a total power requirement of as much as 100 KVA, whereas the critical components of that load may easily be under 10 KVA. It would be far more economical to provide a 10 KVA UPS for the critical loads than try to install a 100 KVA UPS and battery bank.

Table A below illustrates the degree of protection offered by the various choices.

TABLE A

	Brownout	Transient	Blackout	Interrupt	Cost
AC Utility Service	None	None	None	None	0
Line Voltage Regulator	Good	Good	None	None	100%
Engine-Alternator	Good	None	Good	None	300-350%
Uninterruptible Power System with 2 Hour Reserve	Excellent	Excellent	Excellent	Excellent	600-800%

Outside Power Requirements

The outside plant (amplifiers and line extenders) power requirements are considerably different than the head end power requirements. The head end equipment is all designed to be operated from the 120 volt or 208 volt commercial AC service with its smooth sine wave voltage with low harmonic content.

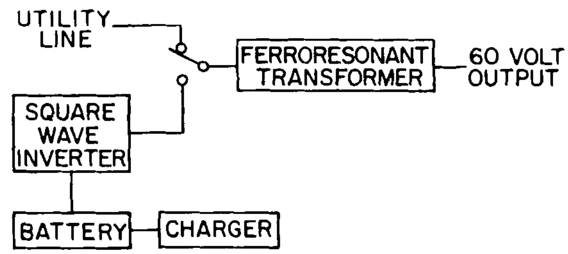
The traditional source of power for the outside plant equipment has been an unfiltered, line operated ferroresonant transformer with an output voltage of 30 or 60 volts and a harmonic content of 15 to 20 percent. The power supplies for the line amplifiers have all be designed to operate satisfactorily from this type of voltage and waveshape.

The 30 or 60 volt ferroresonant power supplies, because they are operating from a standard 120 volt commercial AC service, are all subject to the same power problems that the head ends are subject to. The ferroresonant power supply protects the line amplifiers from the effects of transients and brownouts. There is no protection against blackouts. The line amplifiers receive a limited amount of protection against short interrupts because the ferroresonant transformers contain a small amount of stored energy in the resonant circuit, and the line amplifiers' internal power supply has energy stored within its filter capacitors; thus, the line amplifiers can survive short power line interrupts without affecting the amplifiers operation.

It then becomes necessary to provide blackout and long interrupt protection only to insure continuous operation of the outside plants' electronics equipment. This will necessitate the use of a battery backed up Uninterruptible Power System instead of utilizing the simple ferroresonant power supplies.

The ideal UPS provides an output waveshape that is identical to the waveshape provided by the AC operated ferroresonant power supplies; thus, the line amplifiers will continue to receive the same waveshape in voltage whether it is being supplied by the utility service or by the back up batteries and inverter system.

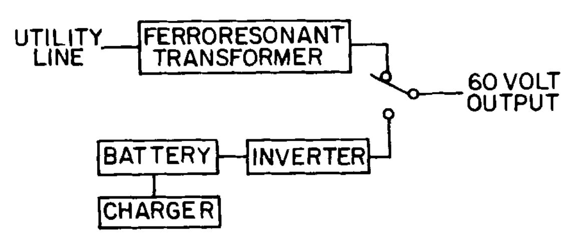
A typical equipment arrangement is shown below.



The utility line is the preferred source of power for the ferroresonant transformer. Should the utility line fail, the square wave inverter is caused to start and the transfer switch switches the output of the inverter to the ferroresonant transformer. Due to the energy stored in the ferroresonant transformer and in the line amplifier power supplies, it is not necessary to have a no-break or an instantaneous transfer from utility line to inverter power. This is unlike the situation at the head end where no energy storage devices are normally employed to keep the computer operated piece of equipment operating during a transfer. The output of the ferroresonant transformer will have the same waveshape and voltage characteristics whether the utility line or the inverter is providing the power to it. It is important, however, that the combination of the transformer and inverter be designed to provide the same level of voltage regulation as the utility line would provide as the battery voltage decreases. During a discharge, the ferroresonant transformer must maintain the output voltage within design limits to assure proper operation of the amplifiers powered by the system.

Following restoration of the utility line, the transfer switch will switch the ferroresonant transformer back to utility power and the battery charger will recharge and maintain the battery.

An alternative equipment arrangement is shown below.



The ferroresonant transformer is again powered by the utility line; however, the output of the transformer is now switched to the inverter and battery combination should the utility line fail. This arrangement does not take advantage of the energy stored in the ferroresonant transformer to help ride through the interruption of the transfer but relies entirely on the energy stored in the line amplifiers' power supplies. The inverter utilized may be one of two different types. The least costly type of inverter is a straight square wave inverter with no regulation. This subjects the load to a wide variation in voltage as the system switches from the regulation inherent in the ferroresonant transformer to the unregulated inverter. As the battery discharges, the output voltage of the inverter will decrease proportionally. An attempt to alleviate the regulation problem is made by utilizing a pulse width modulated (PWM) inverter where the output still is a square wave, but the width of the square wave is caused to vary as the battery voltage decreases in an attempt to maintain a constant output voltage. As the line amplifiers are designed to operate from the wave shape provided by a ferroresonant transformer and not the wave shape provided by a square wave or PWM inverter, the performance of the amplifiers may be adversely affected under worse case operating conditions.

The choice of the batteries and the battery charger employed in the system is vital to assure long term reliability and low cost operation. Two basic types of batteries are available.

1. Float Charge
2. Cycle Charge

The float charge battery is typical of those batteries used in communications service. The battery is designed to have a constant, well regulated battery charger connected to it at all times. The battery charger output voltage must be well regulated to assure that the battery is maintained at a high level of charge, but not at a level that would result in excessive water consumption and degradation of the life of the battery, nor at a level too low to maintain full charge.

An example of a cycle charge battery is the automotive battery. This type of battery is generally lower cost than the float charge battery and will not give long life under float charge conditions; thus, the battery charger must be designed to place a charge on the battery for a period of time, than allow the battery to self-discharge to a lower level, at which time the battery charger is turned on and the battery is cycled up to the fully charged condition. Thus, the state of charge of the battery is constantly changing.

Subscriber Power Requirements

The equipment that the subscriber connects to the cable will increase in complexity as the uses for the cable system increase. Ultimately, his equipment will require the same reliable source of power that the head end equipment requires. Fortunately for the subscriber, the power requirements are generally much lower than the requirements of the head end, but the power problems that the equipment is subjected to are identical. The choice for reliable power that the subscriber will generally make is a small Uninterruptible Power System in the 300 to 1000 watt range. A wide choice of equipment at low cost is available today to assure satisfactory operation of the connected equipment. One should select the UPS that supplies continuous output power without an interruption due to utility line failures and with an output that matches the voltage and waveshape supplied by the utility line to assure satisfactory operation of the connected equipment.

Conclusion

The above discussion has provided a system designer with a brief description of the types of power problems that he must anticipate when designing a total system and discussed the alternatives available today to solve those power problems. Only the system designer can determine which, if any, of the systems described are necessary in his installation , and he alone can select those solutions which exactly match his requirements.

Repeaterless 16 Km Fiber Optic CATV Supertrunk Using FDM/WDM

R. McDevitt, R. Hoss - Warner Amex Cable Communications, Inc.

Acknowledgement: J. Bowen-ITT Electro Optic Products

A key advantage of optical fibers over coax for CATV supertrunk is the elimination of trunk amplifiers or repeaters. By substantially reducing the amount of active electronics associated with supertrunk plant, overall reliability is increased and maintenance costs greatly reduced. Warner Amex is evaluating fiber optics for such an application by way of a field trial in its Dallas network. A 16 Km repeaterless link, is overlashed along an existing cable trunk route, to provide supertrunk quality video signals from the East Master Head End to a hub in the downtown Dallas area. A minimum of four video channels per fiber is transmitted by using two wavelengths per fiber with two frequency multiplexed video channels on each wavelength. A description and results to date of this field trial are presented in this paper.

The Warner Amex Cable Communications network under construction for the Dallas Cable Television Franchise is of a "hub-spoke-rim" design as illustrated in figure 1.0. In this design broadcast signals are distributed over conventional coaxial cable from seven hubs located geographically around the city in a pattern similar to the rim of a wheel. Supertrunks, containing the program channels, radiate, for the most part, from the hub in the center. Trunks vary from 8.9 Km to over 20 Km in length. A secondary diversity interconnect around the rim is accomplished using Microwave Amplitude Modulated Links (AML) to be used in the event service is interrupted in the "spoke" supertrunk. The design is for a full 100 channel capacity distributed from each hub. Channels originate from a Master Head End to the east of town. A 16 Km supertrunk carries these channels to the center hub, for distribution to the hubs on the spoke supertrunk cables. Presently the network is made operational using the AML microwave "rim" interconnect. The "spoke" interconnect, which will become the primary trunk network, will begin construction in 1984. At completion, full redundant signal paths will exist for the interconnect of programs to each distribution hub, making the Dallas CATV system design the highest reliability large scale CATV system in the world.

The planned technology for the "spoke" interconnect is fiber optics. In contrast to the other technologies, optical fibers have the potential for very long repeater spacings, vastly greater reliability due to the reduction or elimination of amplifiers, reduced cable size, and superior signal quality with no susceptability to external radio frequency interference.

In an effort to evaluate the practical use of fiber optics technology for this network, a 16 km repeaterless supertrunk evaluation link will be installed in Dallas. The evaluation will test a four channel per fiber configuration, with end to end performance per channel of a 55 dB weighted peak signal to RMS noise. The potential of 6 channels per fiber will also be evaluated.

The fiber optics supertrunk system design is illustated in Figure 2. The system multiplexes four frequency modulated video channels on a single fiber using frequency division and wavelength division multiplexing (WDM). The system accepts four baseband color video inputs with their companion audio. The companion audio, on a 5.8 MHz carrier, together with the video baseband forms the composit signal which is FM modulated. Wide deviation modulation, 8 MHz peak-to-peak, is used to achieve the maximum improvement factor while maintaining a reasonable channel bandwidth for multiple carrier transmission.

Carriers of 30 MHz and 70 MHz were chosen to allow for the 36 MHz RF bandwidth of the FM modulators. The FM modulated carriers are combined in pairs onto two fiber optic laser transmitters operating at different wavelengths. Wavelengths of 1.2 um and 1.3 um +/- .02 um were chosen for the reasons that laser sources are available at these wavelengths, high signal isolations can be achieved with practical wavelength multiplexers, and moderately priced fibers can be obtained with very low loss and high bandwidths at these wavelengths. The two laser optical outputs are combined in a passive optical wavelength division multiplexer and transmited on a single graded index multimode fiber. The WDM couplers were specified to achieve 30 dB of optical isolation (60 dB electrical) and optical insertion loss values of 1.75 dB max. The WDM couplers are spliced to "pigtail" fibers which are coupled to the lasers and detector diodes. The coupler is them mated with the transmission fiber thru an optical connector.

At the receive end the signals are optically separated by wavelength and converted to electrical signals with a photodetector followed by an amplifier. The resultant RF signal consists of 30 MHz and 70 MHz FM modulated carriers. These carriers are separated and demodulated to produce baseband video and audio signals.

With fiber optic cable over 30 fibers can be contained in a cable which is less than the diameter of a single conventional 0.750 inch trunk cable. At four channels per fiber a 100 channel cable can be achieved with 25 fibers.

Link Budget

The optical link power budget used to specify and design the four channel per fiber configuration is shown in table 1.0. The power output of the laser, coupled into a "pigtail" fiber, is 1 milliwatt or 0 dBm, a practical value for available long wavelength semiconductor lasers. The next component in the link is the WDM coupler. This coupler maintains an optical insertion loss to less than 1.75 dB per end. The optical connector which mates the coupler to the transmission fiber is specified at 1.5 dB per connector, a value achievable with butt contact connector types.

An optical fiber rated at 1 db/Km attenuation was specified. Allowing for a worst case added cable induced attenuation of 0.4 db/Km this would yield a net loss of 22.4 dB over the 16 Km length. Since the cable comes in reels from 1 to 2 Km long, the cable will be spliced at various points along the route. Eight splices at an average splice loss of 0.25 dB were used for the design.

As shown in Table 1, the summation of optical power and link losses results in a -32.9 dBm optical power at the receiver. Receiver sensitivity is referenced to a 30% source modulation index and a CNR of 21 db delivered to the FM demodulator. This is the minimum required to achieve a 55 db weighted SNR for the demodulated baseband video. Receiver sensitivity was calculated to be -36.6 dB. As shown in Table 1, the summation of power and loss leave an excess power margin of 3.7 dB.

Table 1

Optical Link Power Budget

Design Objective

Transmitter Average Coupled Power	0 dBm
Wavelength Division Mux Insertion Loss (Pair)	-3.5 dB
Fiber Attenuation (16 Km)	-16.0 dB
Excess Cable Loss	-6.4 dB
Splice Loss (8 splices)	-4.0 dB
Connector loss (2 connectors)	-3.0 dB
	-32.9 dB
Receiver Sensitivity for 21 dB CNR	-36.6 dB
Excess Optical Power Margin	3.7 dB

Although it appeared that the optical power budget was adequate for the desired systems performance, another factor which may limit the system carrier to noise was evaluated. Noise associated with the laser source, and optical mode interactions within the fiber, pose an upper limit on transmitted carrier to noise. Stable multimode sources were used in order to minimize these effects.

Bandwidth of the various components were specified in order to achieve an overall electrical bandwidth of 90 MHz minimum for the 16 Km link. The laser transmitter has a bandwidth of approximately 500 MHz, and as such can be ignored. The receiver bandwidth is set at approximately 1.3 x 90 MHz=117 MHz for optimal detection. The fiber optical bandwidth must be sufficient to support this. It is known that some bandwidth improvement is gained thru concatenation, i.e., the splicing together of long lenghts of fiber. The relationship is as follows:

$$BW_F\ (\text{MHz-Km}) = BW_T\ (\text{MHz})\ (1 + (L-1)^{\gamma})$$

where L = length of span in Km

BW_F = optical bandwidth of 1 Km fiber

BW_T = total end-to-end bandwidth required

Optical BW = electrical BW/0.7

therefore:

$$BW_T = \frac{90}{0.7} = 128.7 \text{ MHz}$$

γ = concatenation factor, 0.5 assumed.

$$BW_F = 128.7 \text{ MHz } (1 + (16-1)\ 0.5) = 626.5 \text{ MHz.Km}$$

Allowing for uncertainties in true concatenation improvement and a desire to achieve span lengths beyond 16 Km, an 800 MHz-Km fiber was specified for initial tests.

Test Results

At the date of this writing, tests have been performed on first production hardware over a 16 Km uncabled optical fiber. The validity of using the uncabled fiber for these initial tests has been confirmed with measurements made on over 18 Km of cabled fiber produced to date. Excess cable loss was shown to be negligible on the average, and at worst 0.2 db/Km.

For initial tests seven reels of fiber averaging 2.25 Km in length were spliced together with six fusion splices to form a 15.8 Km link. Fiber tension on the spools was relaxed to simulate the cabled state. Attenuation measurements taken on the sections prior to splicing gave an average attenuation of 0.78 dB/Km at 1.30 um and 0.91 dB/Km at 1.20 um. Average optical bandwidth was 1099 MH-km. After splicing, the full 15.8 Km was measured. The total end-to-end optical bandwidth was 80 MHz or a bandwidth distance product of 1280 MHz-Km. The total attenuation was 12.8 dB at 1.3 um (0.81 dB/Km) and 14.9 dB at 1.2 um (0.94 dB/Km).

The bandwidth result indicated that the concatenation factor was actually 0.945 as shown below

$$(L-1)^{\gamma} = \frac{BWF-BWT}{BWT}$$

$$(15.8-1)^{\gamma} = \frac{1099 - 80}{80}$$

$$\gamma = .945$$

The attenuation results indicate a total spliced fiber related loss of approximately 0.5 dB or 0.083 db per splice on the average. It is suspected that this low attenuation differential is a length related improvement effect on both splice insertion loss as well as fiber attenuation. Individual splice losses, may be higher if measured over short fiber lengths.

Insertion loss results on the optical wavelength couplers as pairs gave: - 3.5 db @ 1.3 um and - 3.5 db @ 1.2 um.

The optical transmitters used in this series of tests used multimode lasers, one at 1.3 um and the other at 1.2 um. Performance of the 1.3 um laser indicated a source CNR of 37 dB at 60% modulation index. Performance of the 1.2 um laser indicated a source CNR of 35 db at 60% modulation index. For these link tests, source power was set at 1.2 mw @ 1.3 um and @ 1.2 um. The 60% modulation index represents two channel per laser transmission.

Optical receiver sensitivity varies as a function of carrier frequency.In the 30 MHz band, the received optical power necessary to achieve the required 21 db CNR was

-32.6 dBm. In the 70 MHz band the required received optical power was -30.5 dBm. With the above described transmitters and receivers integrated with the fiber link, end-to-end performance gave a CNR of 30 dB both at 1.3 um and 1.2 um at 30 MHz; 9 dB above the minimum required. Total path loss was measured to be 21.2 dB @ 1.2 um and 20.4 dB @ 1.3 um. Received optical power was therefore over 11 dB (optical) above required receivers sensitivity. If not for the CNR limitations at the source, this would result in a CNR improvement of 22 db over minimum. It is clear that CNR is dominated by source noise. True optical power margin is large and thus will allow for expansion in length or additional loss factors such as cabling loss or added splices while maintaining signal quality.

Conclusion:

Tests on the 15.8 Km link demonstrate the practicality of transmitting a minimum of 4 channels per fiber over distances of 16 Km or greater, with high quality video. The use of existing components and products to achieve these results shows fiber optics to be a practical solution to repeaterless, long haul video trunking, in the near term. Finally, with the continual development of new products that will increase receiver sensitivity, improve laser output power and stability, we are confident that 6-8 channels per fiber will be achievable in the near future. This coupled with continual component cost reductions will further drive this technology to be the logical CATV supertrunk approach for the 80's.

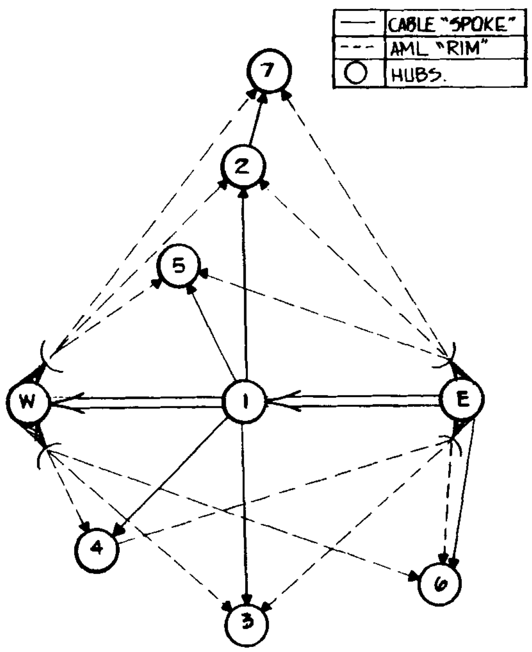


FIG. 1a HUB-SPOKE-RIM IMPLEMENTATION

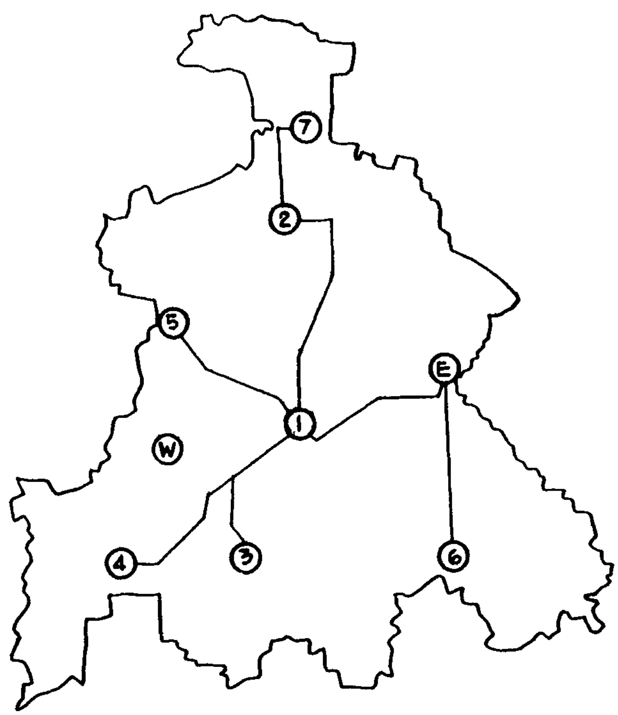


FIG. 1b SPOKE SUPERTRUNK CABLE INTERCONNECT

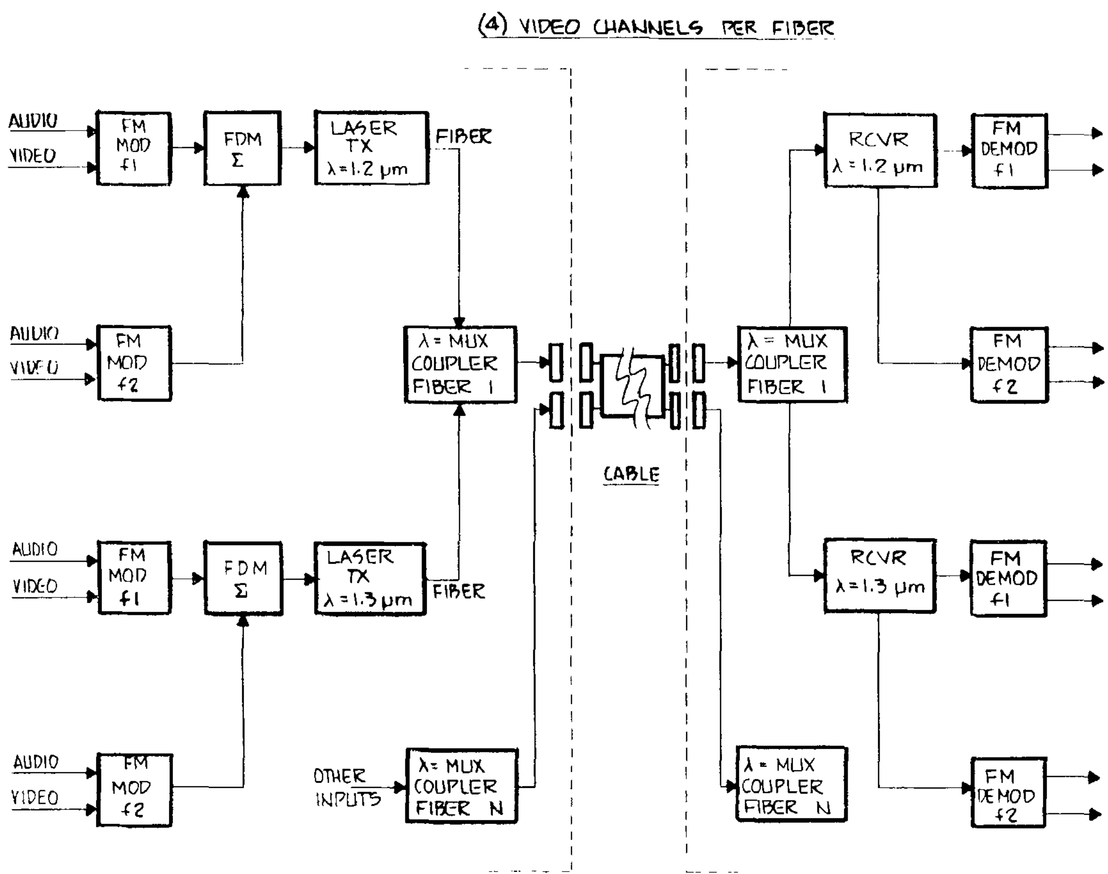


FIG. 2.0 LONG WAVELENGTH FM/FDM/WDM FIBER OPTIC SUPERTRUNK

RETURN SYSTEM SWEEP/BALANCE AND MAINTENANCE

Jonathan R. Ridley

GENERAL INSTRUMENT CORPORATION/JERROLD DIVISION

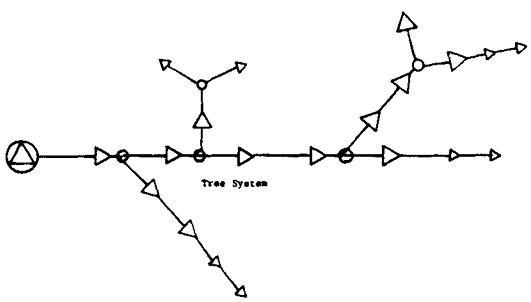
ABSTRACT

With the greater importance of bi-directional video and data transmission in today's cable systems, there now is a greater need for accurate and repeatable set-up procedures and sweep and balance techniques for both the forward and return systems.

This paper will discuss a particular method of return system testing, which will allow for rapid and repeatable system testing. The methodology will be consistent with accepted good engineering practices, so as to afford the operator the assurance of quality test results. The method is cost effective from both the test equipment cost standpoint as well as labor utilization.

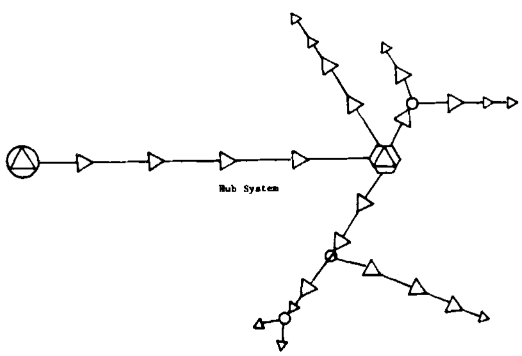
THE STRUCTURE OF THE FORWARD SYSTEM

The basic cable system design performs a dispersal function, whether the historical tree (Figure 1):



(1)

or the hub concept (Figure 2) is utilized.



(2)

In either system, the signals are dispersed to the subscribers from a source, by way of directional couplers (power/voltage dividers). In the forward system, we pay little attention to the impact of uneven directional couplers (voltage/power dividers) other than improving the economy of design.

The system is designed in the trunk or transportation portions around the unity gain concept. That is, the amplifiers are there to make up for losses incurred; external cable and passive losses, or other internal flat losses. A simplistic description of the unity gain concept is as follows:

$$\frac{\text{All losses}}{\text{Gain}} = 1 \qquad (3)$$

This is also sometimes called a zero gain system.

The exception to the unity gain concept in the coaxial cable system is the function performed by the Bridging Amplifier. The Bridging Amplifier is used to elevate the signals above that of the trunk system. This is used to acquire the levels for the distribution system which will allow for design efficiency and cost effectiveness. This is the only place in the system where amplifier gains exceed system losses. In the distribution portions of the system, the unity gain concept is utilized with the line extender amplifier's gain compensating for cable and passive losses.

One of the more critical areas of concern for a unity gain system design and operation is cable equalization over the design bandwidth of the system. In both the forward and return system, correct equalization establishes passive slope correction for cable attenuation. This slope correction ensures consistency and predictability of signal levels to the amplifier. In other words, equalization is used to reestablish the proper relationship of the discrete signal levels across the entire bandwidth of the system. With predictable signal levels and known amplifier performance specifications, i.e. gain, noise figure and output capabilities, the optimum system operating levels can be calculated to acheive desired system performance.

Two distortions, noise, a power function, and composite-triple-beat (CTB), a voltage function, will be the primary offenders to picture quality and, therefore, will be the determinents in developing the operating levels in today's multi channel systems. Both of these distortions are predictable in the cable system and predictability is based on data supplied by the amplifier manufacturers.

We will now establish single amplifier and system carrier-to-noise (C/N) and carrier-to-composite-triple-beat (C/CTB) ratios at normal operating levels from manufacturers' specifications.

Manufacturers' Specifications for Trunk System

Operating Gain = 25 dB
Recommended output level = +32 dBmV
Noise Figure = 7 dB (4)
Composite-triple-beat at operating level = 84 dB
System cascade = 20 Amplifiers

Carrier-to-Noise

Carrier-to-Noise in dB is a function of the amplifier's noise figure and gain expressed as a ratio of the carrier level to the noise level in dBmV across a specified bandwidth. To relate amplifier noise figure to the carrier noise ratio, the following formulas are needed:

C/N = CO - NO
NO = -59.2 dBmV + NF + G
C/N = CO -(-59.2 + NF + G)
C/N System = CO -(-59.2 + NF + G) -10 Log N (5)

Where:

C/N = Carrier-to-Noise in dB
NO = Noise output in dBmV
CO = Carrier output level (6)
IL = Input Level
NF = Noise Figure
G = Gain
N = Number of similar amplifiers in cascade

System noise figure is as follows:

NF system = -59.2 dBmV + (C/N -CO) + G (7)

An example of Figure 5 would be:

C/N = COL -(-59.2 + NF + G) -10 Log N (8)

Where:

NF = 7 dB
COL = 32 dBmV
N = 20
G = 25 dB
C/N = 32 -(-59.2 +7 +25) -10 Log 20
C/N = 46.2 dB

An example of Figure 7

NF System = -59.2 dBmV +(C/N -CO) + G (9)

C/N = 46.2 dB
C/O = +32 dBmV
G = unity or 0

NF System = -59.2 +(46.2 -32) + 0
= -59.2 + 14.2
= dB
NF System = -45 dB

Carrier-to-Composite Triple Beat

Carrier-to-composite triple beat is a function of the operating level of the amplifier and its linearity expressed as a ratio of the output signal level to the output level of all third order distortion products expressed in dB.

Predictability of CTB in cascade is as follows:

C/CTB cascade = C/CTB single amplifier at operating levels -20 Log N (10)

Where:

C/CTB single amplifier = the predicted CTB at operating levels
N = the number of similar amplifiers in cascade

An example of Figure 10:

C/CTB cascade = C/CTB single amplifier at operating levels -20 Log N
= 84 dB -20 Log 20
= 84 dB -26
C/CTB cascade = 58 dB

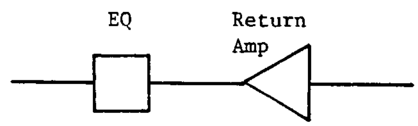
THE STRUCTURE OF THE RETURN SYSTEM

The return system, unlike the forward, is a collector of all information being directed to a focal point; most often the headend. Because of the collection requirements, the use of eneven power/voltage dividers is not recommended. However, economic system design often does not permit this. Similar to the forward system, the return system utilizes the unity gain concept. However, unlike the forward system, which uses pre-equalization almost exclusively, there are two schools of thought on return system equalization. They are:

1. Post-equalization
2. Pre-equalization

Both methods are equally valid. However, there has been much ado concerning the impact of post versus pre-equalization on the system noise figure. Refer to Figures 11 and 12 for an evaluation of Post-equalization.

Post-equalization Block Diagram:



(11)

Where:

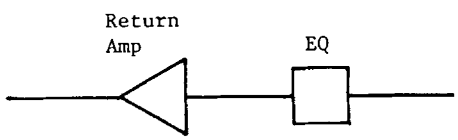
Equalizer loss = 3.6 dB
Cable loss = 6 dB
Input at Amp = 17 dBmV
Gain = 17 dB
Output level = 34 dBmV
Number of return amps = 208

Solve: NO, C/N SA, C/N return system NF return system.

NO = -59.2 + NF + G
= -59.2 + 7 + 17
= -35.2 dBmV
C/N SA = CO - NO
= 34 -(-35.2)
= 69.2 dB
C/N system = 69.2 -10 Log N
C/N = 46 dB

NF system = -59.2 + (C/N system - C/O) + G
= -59.2 + (46 -34) + 0
NF system = -47.2 dB

Pre-equalization Block Diagram:



(12)

Equalization loss = 3.6 dB
Cable loss = 6 dB
Input level = 17 dBmV
Gain = 17 dB
Output level = 34 dBmV
Number return Amps = 208
NF = 7 dB
C/N single amplifier (SA) = 69.2 dB
C/N return system = 46 dB

NO = -59.2 + NF + G
= -59.2 + 7 + 17
= -35.2
C/N SA = CO - NO
= 34 -(-35.2)
C/N SA = 69.2 dB
C/N system = 69.2 -10 Log N
C/N = 46 dB

System noise figure is as follows:

NF system = -59.2 + (C/N -C/O) + G
= -59.2 + (46 -34) + G
NF system = -47.2 dB

It has become obvious that the system noise figure does not change. The only change that can take place is variations in C/N as related to output level. The placement of the equalizer has no impact on the system's noise figure.

Distortions in the return system add exactly as they do in the forward system. Due to bandwidth and resulting limited channel capacity, composite triple beat is not a limiting distortion in the return system. Instead, we find that discrete third order beats, second order beats, and inter-modulation distortions are the limiting distortions.

The manufacturers' specification for discrete third order (B^3) and inter-modulation distortion (IMD) are obtained from data sheets. The formula for third order distortion predictability is:

Cascade B^3 distortion = single amplifier B^3 -20 Log N (13)

Where:

N = the number of similar amplifiers in cascade

For second order beat (B^2) predictability in the cascade, we use the following formula:

Cascade B^2 distortion = single amplifier B^2 -10 Log N (14)

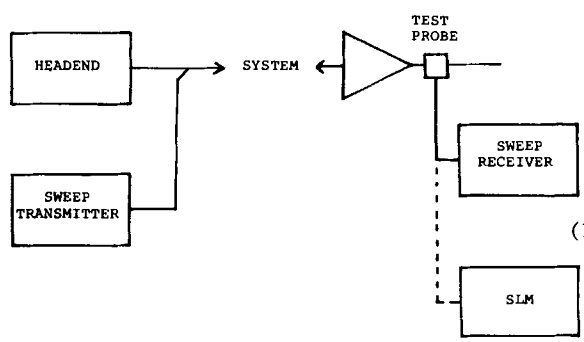
Where:

N is the number of similar amplifiers in cascade

FORWARD SYSTEM SET-UP AND SWEEP/BALANCE

The alignment of modern cable systems must be accomplished through the use of sweep/balance techniques, if the system "flatness" performance that the equipment is capable of achieving is to be realized. System flatness, typically expressed as peak-to-valley, is the measurement of deviations from ideal or design in dB. Sweep/balancing techniques enable the system's engineer or technician to see the effect each alignment control has on the amplifier's response across its entire operating bandwidth. This technique, on an individual basis, allows the operator to fine tune each amplifier in cascade for maximum system flatness.

The set-up and sweep/balance is a straightforward procedure.



(15)

The technician should exercise care in the injection of the sweep signal into the system. Validation of headend levels and sweep response should be logged and photographed, if possible. This documentation of the headend system peak-to-valley is needed to allow the engineer or technician to reference cascade peak-to-valley against the headend to ascertain the real peak-to-valley of the system.

Finally, variable alignment controls within the amplifier must not be used to eliminate excessive peak-to-valley excursions at the amplifier caused by deficiencies in the cable, system's passives or poor splicing. Whenever excessive peak-to-valley excursions are observed at the output test point of an amplifier, it is recommended that the input to the station be checked after equalization, prior to adjusting the variable alignment controls within the amplifier.

Another important aspect of the system set-up, sweep/balance, and preventative maintenance is record keeping. A log should be kept of input and output R.F. levels, AC voltage, and peak-to-valley on each and every amplifier. This is to allow the service technicians to troubleshoot the system rapidly.

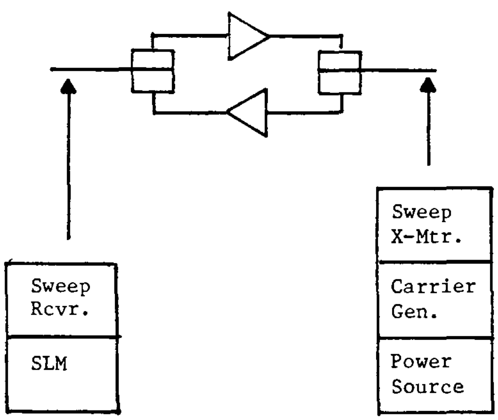
RETURN SYSTEM SET-UP, SWEEP AND BALANCE

There are two methods of setting up the return system using the sweep/balance technique:

1. From the extremities to the headend.
2. From the headend to the extremities.

Figure 16 is a Block Diagram of the test equipment required for Procedure 1:

Block Diagram



(16)

This requires the location of a sweep generator and carrier generator at the extremities of the system, where the technician would begin system alignment. The advantages of this method are:

1. The amplifiers are treated the same as the forward amplifiers.
2. The output of the amplifiers would be flat.

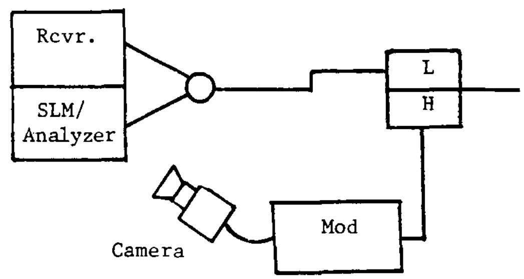
The disadvantages of this method are:

1. It is hard to repeat the set-up throughout the system.
2. Time consuming when sweep/balancing uneven power splits.
3. The expensive piece of test equipment left at the end of the system requires security and/or manpower surveilance.
4. There will be a significant increase in the required number of field calculations.

Now, let us review the second procedure for sweep/balance. This method starts at the headend working towards the extremities of the system. Figure 17 is a Block Diagram of the test equipment required for Procedure 2.

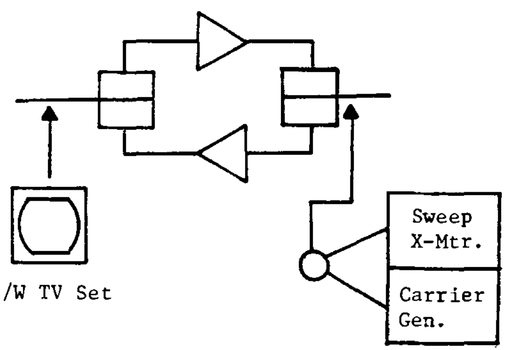
Block Diagram

Headend



(17)

System



Procedure No. 2 is a more direct approach, requiring a sweep receiver, SLM or analyzer, a black and white TV camera and a modulator at the headend, and a sweep transmitter, carrier generator, and a black and white TV set at the amplifier being swept/balanced. The technician has to set up only the correct input level at the sweep injection point to the return amplifier input and then monitor the headend levels and peak-to-valley with the black and white television set. This can be accomplished at the distribution test point or a tap in the forward system. The TV set can be battery operated and taken up to the amplifier, thus utilizing only one technician to perform the sweep/balance. Uneven power splits become unimportant with this balance technique because the system is balanced against the headend for flatness and levels rather than for the specific flatness of an amplifier.

By careful alignment of return system starting at the headend, the system can be set up for repeatable test results. If the sweep injection levels are known, any point in the system can be validated at any time by one person utilizing standard test equipment available at all newer systems. The advantages of the sweep/balance Procedure No. 2 are:

1. Repeatability of measurement.
2. Requires less manpower to perform.
3. Requires less capital equipment.
4. Allows system troubleshooting and repairs from the headend to the terminator.
5. Allows for simultaneous qualification of the return system to the terminator with forward system.
6. Reduces time in testing uneven power splits.
7. Utilizes commonly used test equipment.
8. Requires no guesswork or calculations as to levels or terminator cable or splicing integrity.

SUMMARY

It is obvious, to obtain repeatable and accurate tests of return systems during the operational life of a cable system, that the tests have to be easily accomplished, utilizing a minimum of manpower and capital equipment. The method established as Procedure No. 2 reduces the number of technicians required for return system testing as well as the risk of having unattended high-cost test equipment and vehicles at the system extremities. This procedure establishes defined input levels against defined headend input levels, thus reducing the number of field calculations to one, that is the level of 31.5 MHz at the headend from the first amp. It eliminates the mystique and mystery from return systems testing.

RF CONVERTERS ARE ALIVE AND WELL!

A Technical Update

Lindsay H. Miller

GENERAL INSTRUMENT CORPORATION
Jerrold Div.

With the advent of multi-level pay services, the incidence of theft of service has begun to rise. The Cable Operator in pursuit of a higher degree of security of his services from theft has turned to baseband scrambling techniques. Does this increased popularity of baseband units mean that RF scrambling techniques are a thing of the past? I believe the answer to this is NO! RF has some basic advantages over baseband and its past weaknesses have been overcome.

One of the key advantages which RF conversion and scrambling tecniques have is that they are less costly. Not only are we further down the learning curve in economic manufacturing RF converters, but they are also inherently less costly as they contain fewer components. The costs of manufacturing are not the only costs which are lower with the RF converter. The costs of training technicians to repair baseband converters, the cost of test equipment, the actual cost of repair and the cost of carrying inventory are all areas where RF has an advantage over baseband. In all areas of cost, it can be shown that RF converters with RF scrambling techniques are inherently less expensive.

The perceived downfall of RF converters has been in the area of signal security. At the time that the present sync suppression scrambling methods were developed, multi-level pay and potential $50 monthly fees to subscribers were not even considered. However, as the popularity of cable TV and a proliferation of pay services has occurred, the motivation to steal these signals has increased significantly.

But in order to understand the strengths or weaknesses of a given signal security system, we must understand the methods by which the services are stolen. There are really three categories of theft of cable services.
They are:

1. Subscriber Tampering - This is where a Subscriber gains access to the inside of the box himself and makes minor modifications to the electronic circuitry.

2. Simple Pirate Boxes - These are boxes purchased by the Subscriber which are already capable of receiving pay signals. Typically they are boxes manufactured by legitimate cable TV equipment manufacturers but which contain minor modifications to the electronic circuitry made by the pirate box manufacturer.

3. Custom Pirate Boxes - These are boxes manufactured from beginning to end by illegitimate equipment manufacturers for the sole purpose of stealing cable TV signals.

These three types of signal theft can be looked at from a different perspective. The weaknesses in the scrambling system can be grouped into three classifications which are:

1. Mechanical Security
2. Electrical Security
3. Scrambling Security

Subscriber Tampering involves weaknesses in both electrical and mechanical security. That is, the Subscriber is capable of getting into the box (Mechanical Security) and is able to make a minor modification to get the pay services (Electrical Security). This type of tampering will not be prevented by even the most complex scrambling technique if the mechanical and electrical security aren't there. The same can be said of the simple pirate boxes which are modified by a pirate box manufacturer. The only type of theft of service which is scrambling dependent is the manufacture of a custom pirate box.

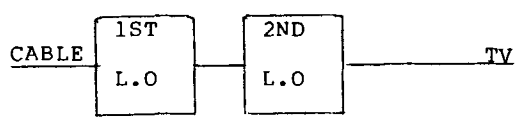
There are presently several methods on the market for preventing access to the box by the Subscriber, but there is only one method which I am aware of which prevents access to the sensitive circuitry by anyone, and that is the potting method used by Jerrold. The potting material is extremely hard and requires a special tool in order to penetrate it. In addition it is impervious to solvents and hence thoroughly protects the electronic circuitry from modification by either the Subscriber or a pirate box manufacturer. Thus we can see that we can solve the problem of mechanical and electrical security with RF converters. The final question we must answer then is can we develop a scrambling method which is secure enough to be very difficult to overcome by a black box manufactured by a pirate box manufacturer.

It is generally acknowledged that a dynamic scrambling system would be most secure. In addition, if the data for properly descrambling that system were encoded, it would become very difficult to defeat the system. A dynamic sync suppression system with encoded descrambling information would be very difficult to beat. The system which we developed at Jerrold for our STARCOM 450 converters meets both of these criteria. We randomly switch between two modes of sync suppression to scramble the picture. The data as to what the next mode will be and when it will occur is encoded. In addition, in our encoder we provide the capability of sending the signal in the clear as a third level of scrambling. Thus we can switch between three modes of sync suppression.

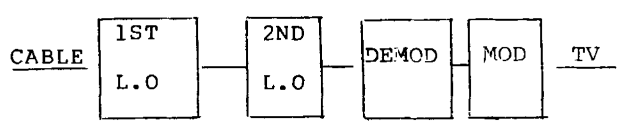
With this type of sync suppression an existing 6 dB descrambler would see a picture only a portion of the time. The rest of the time the picture would look scrambled just as it does on a plain box on the 6 dB scrambling system today. If the box were modified to some other static descrambling level, there would be at best tremendous changes in the brightness of the picture. We believe that the general public would not pay very much for a pirate box of this type and hence no one would supply this type of box. As a result, we believe that an RF scrambling system can be made very secure.

But this is not the whole story. RF has other advantages over baseband which argue for its use. An RF converter with RF scrambling by nature has better performance than a baseband unit, especially a baseband unit with video inversion. As we can see from the block diagram in Figure 1, the baseband converter has inherently more signal processing circuitry. In fact, the RF descrambler is merely a passive device which does not affect linearity. Thus differential phase and differential gain are maintained. In addition, the picture is free of 920 KHz beats formed as a result of the demodulation/modulation process. Because there are no inter-carrier spacing problems no FCC waiver is required as with some baseband converters (the Jerrold STARCOM V does not require this waiver). Because AGC is not required in the RF converter it has better overload characteristics. For a scrambled signal, the switched passive system of the RF converter introduces no additional non linearities and hence is superior. It might be noted also that sync suppression when done on all blanking intervals as done by Jerrold, reduces the total power of the system by about 3 dB. Thus the overall performance capability of RF converter with descrambling is superior to a baseband converter.

FIGURE 1



RF CONVERTER



BASEBAND CONVERTER

Last, but by far not least, is the inherent reliability of the RF converter. With the new digital designs being implemented on RF converters, the reliability has been greatly enhanced. In addition, we are well down the learning curve in the manufacture of the RF converter. As a result, testing processes, component selection, mechanical design and all the other parameters contributing to reliability of the product have been thoroughly engineered. Because of the prevalence of the RF converter, they are much easier to get fixed. There are many more technicians trained in the repair of RF converters and there are many more companies and repair centers that are capable of repairing the RF converters. Finally, because there are fewer parts in an RF converter there are fewer things to go wrong.

The question implied in the title of my paper has been answered. RF converters will continue to be a viable approach to signal delivery for Cable Operators. RF Converters are the most cost effective approach to video tuning and signal descrambling. With the new dynamic sync suppression systems, signal security is much improved and should take us forward through the multi-level pay area of CATV. In spite of the hype on the high technology baseband converters, it can be seen that RF converters have inherently better performance and are more reliable. Therefore, I believe that the RF converter remains the most cost effective approach for the Cable Operator to offer pay services to his Subscriber today.

SECURING A SATELLITE DISTRIBUTED TELEVISION SIGNAL

Paul A. Heimbach
Director, Engineering Planning and Development
Home Box Office, Inc.
1114 Avenue of the Americas
New York, New York 10036

Satellite Scrambling Design and Implementation

Beginning this year, Home Box Office, Inc., will scramble its HBO satellite-delivered programming. The scrambling system will provide highly reliable, trouble-free operation with minimal signal degradation due to the scrambling/descrambling process. Actual system parameters conform to HBO's rigorous Satellite Security System Design Target for performance, operation and security. A very high degree of signal protection is provided by digitally achieved combinations of encryption and scrambling techniques based on the National Bureau of Standards' Data Encryption Standard. The Data Encryption Standard is the foundation for highly sophisticated encryption and key distribution functions.

Each descrambler is addressable and fully controlled from the HBO origination facility. Operator attention to the descrambler is limited to the installation, initial settings of audio and video levels, and periodic maintenance.

This paper discusses the relevant technical details of the scrambling system.

Introduction

In December of 1983 Home Box Office, Inc. (HBO) will scramble two of its satellite distributed entertainment channels using the M/A-COM Linkabit VideoCipher scrambling system. The VideoCipher system uses a combination of analog and digital techniques to process and scramble the audio and video components and, through the application of a very secure data encryption algorithm, renders the scrambled signal useless to all but authorized users.

HBO sells premium programming to cable systems in the United States. The method of program distribution is domestic geostationary satellite. Programming is uplinked to the satellite where it is translated in frequency, amplified and downlinked to the U.S. in a national coverage beam. These downlinked signals can be received by authorized and unauthorized users alike, using receiving antennae as small as three meters in diameter. Today the private user can purchase an adequate receiving system for under $2,000 U.S. According to some estimates, 30,000 private systems are already in operation and new private systems are growing at the rate of 2,000 per month. It is in this context that HBO made the decision to scramble its satellite distributed premium programming.

Securing the Signal

The primary goal of scrambling is to render the program undesirable to unauthorized users. The signal can be rendered undesirable to a degree by scrambling only the audio and/or video and made totally undesirable to an unauthorized user by scrambling both the audio and video. Value or desirability exist in both the audio and video as individual components; therefore, both should be scrambled.

Securing the Audio Signal

From HBO's experience of evaluating many satellite security systems, it is apparent the most desirable method of securing the audio portion of the signal is to first digitize the audio, apply a very secure data encryption algorithm to the digital audio bits and transmit the audio channels in a digital format. The digital stream is then decrypted at the descrambler location and converted back to the analog format for distribution. The advantage of processing and transmitting the audio digitally is that any encrypting algorithm can be completely removed by the descrambler. Artifacts of the scrambling process are virtually nonexistent. Furthermore, a much higher quality signal can be delivered to the cable headend and eventually to the individual cable subscriber. And, finally, application of digital sound in sync allows full transponder power to be devoted to both the audio and video separately, improving the video signal-to-noise ratio.

Securing the Video Signal

Securing the video portion of the signal offers a variety of methods, each with its advantages and disadvantages. There are two basic methods of scrambling the video signal: (1) Amplitude variations and (2) time shifting various components of the video waveform. While these two methods present the possibility of many variations, only basic characteristics will be discussed here, citing both advantages and disadvantages of each.

Variation of the signal amplitude can range from simple synchronizing pulse suppression or elimination to variations of the amplitude of the active portion of the video signal, such as video inversion. Both analog as well as digital techniques can be used. Generally speaking, the amplitude variation method of scrambling is easier and in some cases less expensive to implement than the time shifting technique. Fewer components are required, making the construction easier and less costly and also aids in improving the operational reliability of the equipment. This method of scrambling the video is highly sensitive to signal path nonlinearities. Therefore, one must remember that the satellite distribution link including uplink, satellite transponder and downlink receivers (up to 50 different kinds in HBO's distribution path) has the potential to be unpredictably and uniquely nonlinear for each receiving location. This nonlinearity in the system makes artifact-free reconstitution of the amplitude varied signal difficult. In scenes of low luminance levels, as often occurs in movies, as little as 1/3 IRE luminance variation is observable. If the video signal is amplitude varied in a changing pattern at line rate, the observed effect is a streaking or dancing of individual lines. Variations at field or frame rate appear as flicker. It is conceivable nonlinearity correcting circuits can be designed to compensate for the link differences. However, these circuits add to the cost, reduce reliability and raise questions as to their ability to correct all link distortions one might encounter.

Time shifting various components of the video signal is based on the concept that the link characteristics, while variant with video amplitude are invariant over short periods of time ranging from line time to field time. In other words a video line transmitted over the link at time t_0 or t_0 +4 lines will be transmitted in essentially an identical manner, and will not be degraded simply because of the timing of its transmission. Line permutation or rotation are two methods whereby the video signal is shifted in time. Virtually artifact-free reconstitution of a time shifted signal can be accomplished. While time shifting can be done both digitally and using analog methods, it appears to be more expensive and complex than amplitude variation systems.

An approach suggested but quickly dismissed was one in which the video is digitized; each bit of the digital video signal "exclusive or'ed" with a pseudorandom bit stream, converted back to an analog signal and transmitted. Reconstitution is performed using the same method and same pseudorandom bit stream. Unfortunately, this scrambling technique has the potential of generating frequency components well outside the normal video bandwidth, making it impractical for use on most video transmission links.

Degree of Security

Because the downlinked signal is available to all who wish to receive and try to descramble it, the degree of security must be exceptionally high. To this end, nonchanging scrambling methods, such as constant video inversion or fixed line permutation or changing scrambling patterns based on a limited number of fixed patterns, are totally unacceptable. Through the appropriate application of proven encryption algorithms, apparently random patterns can be generated and applied to both the audio and video components. The mere fact alone that millions upon millions of scrambling combinations can be generated provides all the needed security. The basic security system must be based on an encryption algorithm still unbroken. However, if the algorithm should be broken, manufacture of unauthorized descramblers on a small scale must be prohibitively expensive.

HBO's Selected System

HBO selected the scrambling system demonstrated by MA-COM Linkabit, a U.S. manufacturer of high technology devices including data encryption systems and devices that brought back pictures from Jupiter and Saturn. The M/A-COM Linkabit system meets or exceeds the design goals set forth in a 57-page document prepared by HBO. The design goals included audio and video performance, operational characteristics, reliability and security requirements and environmental considerations.

The video signal is processed digitally, with scrambling accomplished by time shifting various portions of the video signal. Sampling of the video signal is at four times color subcarrier in the scramblers and descramblers, with the scramblers and the descramblers sampling to eight bits. The digitized scrambled signal is converted back to analog form closely resembling a standard NTSC signal for transmission. The reconstituted analog signal does not contain frequency components outside the standard NTSC video spectrum. Tests conducted on satellite link simulators, actual satellite links and through devices capable of adding controlled distortions have shown that the reconstitution of the scrambled video signal is free of artifacts.

The video signal is scrambled in any one of 50 million ways each frame time, with the actual scrambling pattern selected by the judicious applications of a pseudorandom binary sequence. Pattern changes are made many thousands of times a second, rendering the picture unrecognizable and impervious to descrambling attacks, such as line correlation techniques and pattern recognition.

With the output of the scrambler connected to the input of the descrambler, the system exhibits a minimum weighted video S/N of 57 dB, differential phase and gain less than 2° and 2 percent respectively and a frequency response of $\pm$ .5 dB, DC to 4.5 Mhz. All additional standard video parameters are specified and held to tight tolerances.

Two channels of audio are linearly sampled at a rate of 44.056 k samples/second, with 15 bits per sample. The digitized audio channels are then companded and error correcting codes are applied to the resulting bits prior to transmission. Scrambling of the audio channels is done by "exclusive oring" each audio bit with a bit from a pseudorandom bit sequence.

The digital audio channels, as well as the control and message channels, are transmitted in the scrambled video signal during the time normally occupied by the horizontal sync pulses. A residual sync tip of about one microsecond remains in the transmitted signal for use in circuits with sync tip clamps. Placing the digital audio channels in the horizontal sync interval allows 100 percent of the uplink and downlink power to be applied to both the audio and video channels. Approximately 2 dB of video S/N improvement is gained, along with the elimination of interference caused by co-resident subcarriers. Data capacity is also limited by the data in sync transmission, but the need for more than two very high fidelity audio channels does not currently exist in the U.S. Furthermore, if additional data capacity is needed at a later date, co-resident data carriers can be added within the transponder without obsoleting the existing scrambling system.

The audio output of the descrambler is presented in both an analog format and a digital format. If a descrambler is not authorized, the analog audio outputs sound like white noise, and the digital outputs appear to be random bit streams with no relationship to the original program audio. The audio S/N is at least 60 dB reference to 0 dBM. Clipping occurs at +20 dBM and the system frequency response is $\pm$.25 dB, 20 Hz to 15 Khz, with total harmonic distortion less than .2 percent.

U.S. cable operators generally operate their receiving equipment to present a carrier-to-noise ratio greater than 11 dB. Under these circumstances there is no impairment to the audio and video signals. To provide a margin of safety, the system operates reliably at a carrier-to-noise ratio of 9 dB, exhibiting no more than one audio click in a ten-minute period per channel, solid video reconstruction, no loss of descrambler synchronization and less than one second for descrambler synchronization acquisition. Test results have shown the M/A-COM Linkabit system continues to present acceptable audio and video at carrier-to-noise ratios of less than 9 dB.

Within the next year, the scrambling system will be in the HBO signal path that feeds 11 million subscribers. Reliability of the equipment is, therefore, very important. At the HBO uplink, the scramblers will be installed in a primary/hot backup configuration. If a deviation from normal operation is detected in the primary scrambler, all audio, video and control inputs will automatically switch to the backup scrambler. The input of the uplink exciter will switch from the output of the primary scrambler to the output of the backup scrambler. Should the backup unit fail while it is online, the system will switch to complete signal bypass. In this mode, the video is fed unscrambled to the uplink exciter, the stereo audio channels are combined to form a monaural channel which is fed to the 6.8 Mhz aural subcarrier modulator, auxillary contacts turn on the aural channel and the program is transmitted unscrambled as it is today. In the event of a partial failure, both the scramblers and descramblers revert to a special mode, which is as secure but does not require computer management.

Each descrambler is able to recognize a scrambled or unscrambled transmission. If the signal is scrambled, only authorized descramblers will descramble the audio and video. Unscrambled transmissions, however, cause all descramblers to go to bypass mode. The audio and video outputs from the satellite receiver are routed around the descrambler's electronics and presented at the descrambler's video and analog audio output connectors.

In HBO's application of the scrambling system, descramblers will be located at unmanned sites, some inaccessible for three or four months out of the year due to weather conditions. The descramblers, therefore, are reliable, maintenance free and rugged. The design of the descramblers provides a calculated Mean Time Between Failure (MTBF) of 16,000 hours. Experience has shown that standard MTBF calculations are pessimistic and an even greater MTBF can be expected. Like the scramblers, the descramblers can be installed in a primary/automatic backup configuration. This feature is optional, to be used at the descretion of the cable operator. If this option is elected, the MTBF of the descrambler configuration is increased many fold.

Periodic adjustment of the descramblers is not required. At the time of installation, the audio and video gains of the descrambler are adjusted to be compatible with the associated satellite receiver and CATV modulator. No further adjustments are required throughout the operational period of this configuration. Additionally, all descrambling control information is transmitted to each descrambler by the scrambled signal path, thus freeing the cable operator from the responsibility of having to enter the descrambling messages.

Generation of the scrambling/descrambling pseudorandom bit streams and distribution of descrambling messages are the foundations of the system's security. Message distribution is complicated by the fact that it is sent in band along with the scrambled signal. A very effective approach to maintaining security integrity uses a combination of very secure data encryption algorithms and a unique identity for each descrambler.

The National Bureau of Standards' Data Encryption Standard (DES) is used to secure all message transmissions as well as generate the necessary pseudorandom bit sequences. The DES algorithm has been available to the U.S. public for a number of years, and despite repeated attacks has not been compromised. We feel confident the application of the DES algorithm meets HBO's security needs. Furthermore, because the bit sequences change many times a second, the possibility of code pattern detection is virtually impossible.

Assigning a unique identity to each descrambler offers protection against duplication of authorized descramblers. Cloned descramblers, once identified, can very easily be traced back to the parent authorized descrambler's identity. Once the authorized descrambler is identified, it is simply deactivated. As a result, the authorized as well as the duplicate units will cease to operate. Addressability is also made possible by the assignment of unique descrambler identities. Very large quantities of descramblers in any quantity and combination can be activated on an apparent instantaneous basis.

HBO's intention is to install a scrambling system that is virtually transparent to the audio and video signals, highly secure, reliable and capable of future growth. Additionally, HBO hopes to have defined a system that will meet most users' needs and be capable of forming the core of signal scrambling devices. Years of effort, research and working with manufacturers has gone into this system, and we are confident the M/A-COM VideoCipher will meet all these requirements.

SOME CONSIDERATIONS FOR APPLYING SEVERAL FEEDFORWARD GAIN BLOCK MODELS TO CATV DISTRIBUTION AMPLIFIERS

John C. Pavlic
Engineering Manager, Distribution Products

C-COR ELECTRONICS, INC.
State College, Pennsylvania

Abstract

Many systems are being designed with amplifiers containing Feedforward technology because of its improved dynamic range over conventional push-pull hybrids. All Feedforward amplifying stages achieve this improved distortion performance by cancelling the distortion created in the stage's main amplifier. During the process of designing a Feedforward amplifying stage for use in trunk amplifiers, four circuits were modeled that would fulfill the basic requirements of a Feedforward amplifier stage. These four circuit models are presented with the operational advantages and disadvantages of each. In addition, the performance characteristics of several trunk stations using the most advantageous Feedforward circuit models are compared to each other and to conventional push-pull type trunk stations. The performance characteristics of several line extenders using the most advantageous Feedforward circuit models are also presented.

1. Introduction

Since the advent of Feedforward technology, its operational benefits and usefulness have not been well defined. We believe some insight into Feedforward theory would be helpful. Our purpose is to answer three basic questions. These are:

1. What is the optimum Feedforward gain block configuration?
2. What is the optimum Trunk Station configuration using Feedforward gain blocks or standard push-pull hybrids in conjunction with a Feedforward gain block?
3. Is the optimum trunk Feedforward gain block also the optimum for line extender amplifiers?

2. Designing an Optimum Feedforward Gain Block

The first consideration was to evaluate several Feedforward gain block configurations. We weighed the following characteristics: Gain, Noise Figure, Distortion Performance, Maximum Reach, and Power Consumption. Figure 1 illusrates the signal path of a Feedforward stage from input to output. Each characteristic of the Feedforward amplifying stage will be discussed separately to demonstrate how performance is determined.

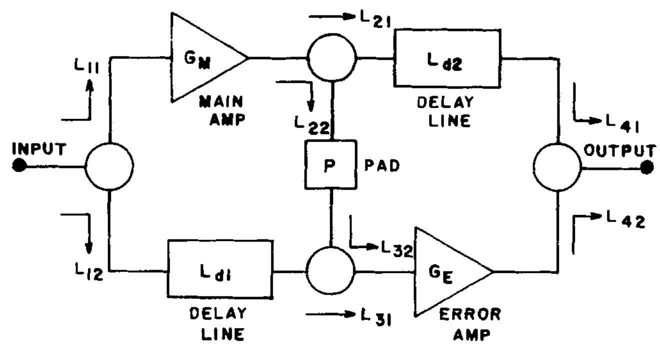


FIGURE I
FUNCTIONAL BLOCK DIAGRAM OF A FEEDFORWARD GAIN BLOCK

2.1 Gain

The first design rule is that gain of a Feedforward Amplifying Stage equals the gain in the signal path minus incurred losses.

$$G_{FF} = G_M - L_{11} - L_{21} - L_{d2} - L_{41} \quad (1)$$

Where: G_{FF} = gain of the Feedforward Stage,
G_M = gain of the main amplifier,
L_{11}, L_{21}, L_{41} = coupler losses, and
L_{d2} = second delay line loss

The second rule is that gain of the signal path input to output in the stage equals gain of the error path. This assumes $L_{21} = L_{31}$. That is:

$$G_M - L_{11} - L_{21} - L_{d2} - L_{41} = G_E - L_{12} - L_{d1} - L_{31} - L_{42} \quad (2)$$

Where: G_E = error amplifier gain,
L_{12}, L_{31}, L_{42}, = coupler

losses, and
L_{d1} = First delay line loss

Equipped with Equations 1 and 2, the circuit designer can model several Feedforward gain stages using standard hybrids for G_M and G_E. The four circuit models in Figure 2 represent the only possible configurations left to the designer, since Equation 2 limits the circuit losses.

2.2 Noise Figure

Noise Figure of Feedforward gain stage is determined by the noise performance of the error amplifier leg. Since the noise produced by the main amplifier is canceled by the first loop, the Noise Figure of a Feedforward stage can be calculated in the following manner.

$$NF_{FF} = NF_{GE} + L_{31} + L_{D1} + L_{12} \quad (3)$$

Where: NF_{FF} = Noise Figure of the Feedforward stage, and
NF_{GE} = Noise Figure of the error amplfier

2.3 Distortion Performance

Assuming that the limiting performance parameter is composite triple beat, distortion performance of the Feedforward stage is determined by the distortion produced by amplifier G_M and the distortion improvement factor K_D. Distortion improvement factor is a measure of the increase in output capability of the Feedforward stage as compared to the output capability of G_M. The amount of distortion cancelation achieved by the error amplifier loop is directly proportional to the amplitude and phase balance within loop. It has been determined that 24 to 25 dB of cancelation can be realized if the amplitude balance is within .25 dB peak-to-valley and the phase error is held within 2 degrees.[1] K_D is the distortion cancelation accomplished in the loop minus the circuit losses incurred between G_A and the Feedforward stage output. The distortion improvement factor, therefore, is:

$$K_D = \frac{24 - 2(L_{21} + L_{d2} + L_{41})}{2} \quad (4)$$

Where: K_D = the distortion improvement factor, dB

2.4 Maximum Reach

Maximum reach is the longest cascade in dB that the gain blocks can be cascaded given a specific noise and distortion performance.

The hybrids used in the Feedforward circuits have a noise figure of 6 dB and a 56 dB carrier-to-composite beat performance at +46 dBmV flat output, loaded to 450 MHz with 60 channels. Maximum reach is a system with a desired 43 dB carrier-to-noise ratio and 59 dB carrier-to-composite triple beat ratio. Maximum reach can be calculated from the following equations.

$$R_{max} = N \times G_{FF} \quad (5)$$

$$N = 10^X \quad (6)$$

$$X = \frac{Vspec - Vopt}{10} - \frac{59 - CCTBspec}{20} \quad (7)$$

$$Vopt = Vspec + \frac{43 - CNRspec}{2} - \frac{59 - CTBspec}{4} \quad (8)$$

Where: R_{max} = maximum reach in dB,
N = number of gain blocks in cascade
Vspec = specified gain block output level,
CCTBspec = Specified gain block carrier-to-composite triple beat ratio, and
CNRspec = specified gain block carrier-to-noise ratio

2.5 Feedforward Circuit Models

To evaluate gain block performance (Figure 2), we assume the same noise and distortion assigned to G_M and G_E gain blocks. The blocks use standard values of G_M and G_E. Then gain, K_D, N_F, power consumption, and reach are calculated using Equations 1, 3, 4, 5, 6, 7, and 8. Table 1 gives comparisons.

	FF1	FF2	FF3	FF4
Gain, dB	23	18	18	24
NF, dB	9	16	9	12
K_D, dB	9	9	2	6
R_{max}, dB	1725	846	1134	792
Power, W	16.3	13.4	13.4	16.3

TABLE 1
Comparison of Performance of Several Feedforward Gain Blocks

FF1 is, therefore, the optimum gain block; it simultaneously produces minimum noise and maximum distortion cancelation. FF1 also provides maximum cascade when analyzed for trunkline use. FF2 is also attractive, even though its noise is high. The performance of each gain block is given in Table 1.

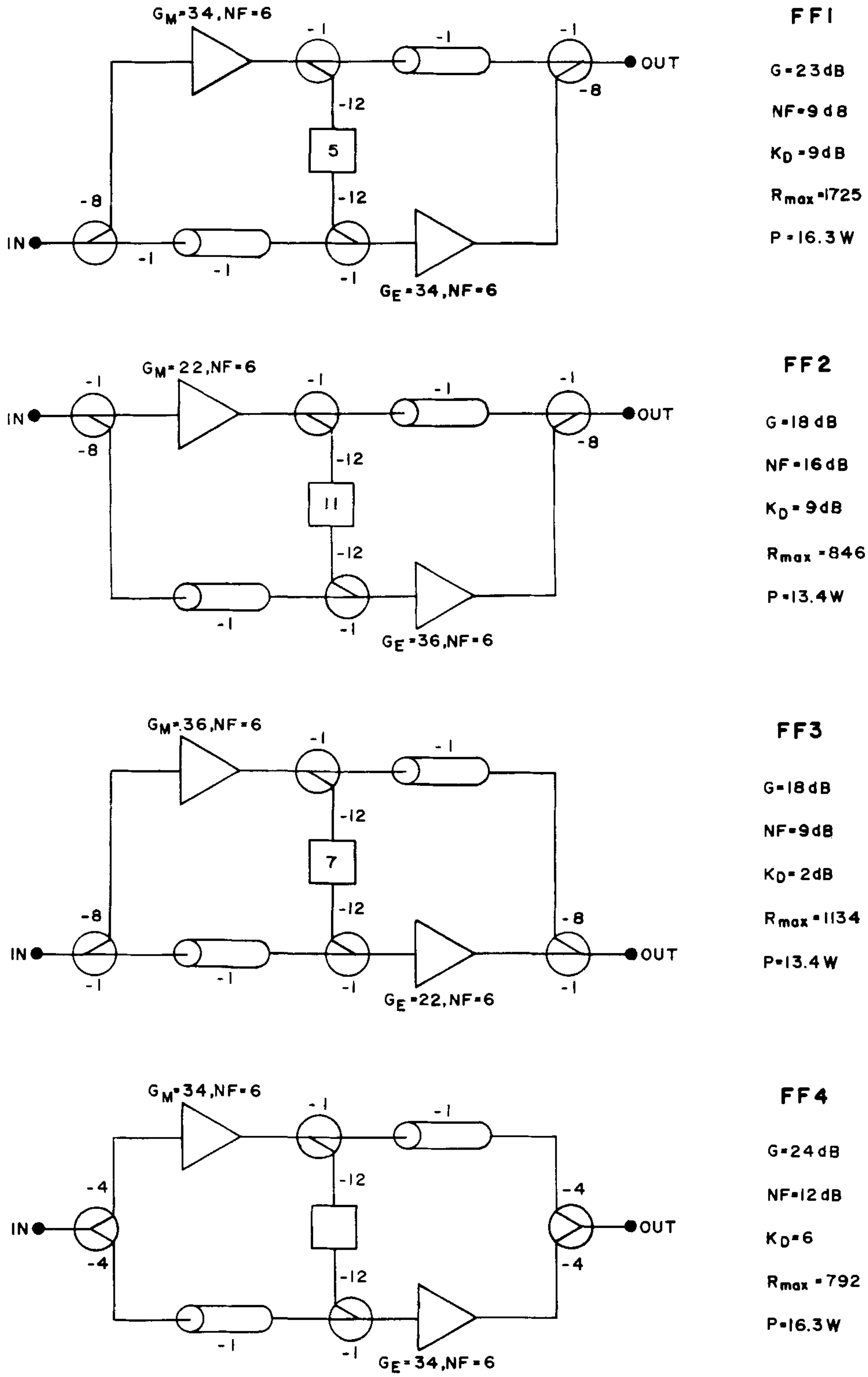


FIGURE 2

SEVERAL FEEDFORWARD GAIN BLOCKS

3. Configuring a Trunk Station.

Figure 3 illustrates a generic trunk station with two amplifying stages, G1 and G2, and losses from housing, slope, gain, PIN Diode attenuator, and an automatic level control/bridger amplifier sampling circuit.

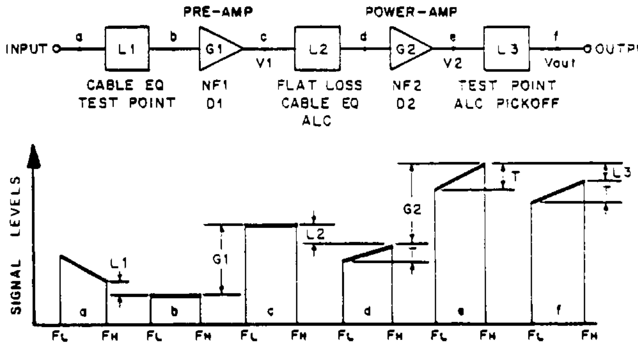


FIGURE 3
TRUNK STATION CONFIGURATION

Since FF1 and FF2 have advantages previously noted, we will model those gain stages into the trunk station in Figure 3. The distortion specifications in Table 2 were calculated by applying the distortion improvement factor, K_D, to the following equation.

$$D_{FF} = D_{GM} - 2K_D \qquad (9)$$

Where: D_{FF} = distortion of the Feedforward gain block at 46 dBmV out, 60 channels flat, and
D_{GM} = distortion of G_M at 46 dBmV out, 60 channels flat

Gain Block	Gain, dB	CCTB* dB	NF, dB	Power, Watts
FF1	23	74	9.0	16.3
FF2	18	74	16.0	13.4
GB12	12	58	8.0	4.8
GB18	18	58	6.0	5.8
GB22	22	56	6.0	5.3

*46 dBmV out, flat, 60 channels, 450 MHz

TABLE 2
Comparison of Performance of Several Gain Blocks to be Used in Trunk Design

Table 2 lists distortion performances of FF1 and FF2 as well as several standard push-pull hybrids specified at +46 dBmV out, 60 channels flat. With information from Figure 3 and Table 2, we modeled several trunk amplifiers and evaluated their performance. Trunk model evaluation was based on specifications of trunk spacing, optimum output signal level, carrier-to-composite triple beat ratio, carrier-to-noise ratio, noise figure, maximum cascade in dB maximum number of amplifiers in cascade, and power consumption. These specifications were drawn as outlined below.

3.1 Trunk Spacing

Trunk spacing is the maximum cable distance in dB at the highest operating frequency at which the station can be placed. Measured at 70°F, spacing includes all circuit losses and the reserve gain required for automatic level control.

$$GT = G1 + G2 - L1 - L2 - L3 \qquad (10)$$

Where: GT = trunk spacing,
G1 = gain of G1,
G2 = gain of G2,
L1 = 2.5 dB,
L2 = 10.0 dB, and
L3 = 1.5 dB

or,

$$GT = G1 + G2 - 14 \qquad (11)$$

3.2 Optimum Output Signal Level

Optimum output signal level is the station output level that permits maximum cascading of amplifiers while still meeting system performance requirements for both carrier-to-noise and carrier-to-composite triple beat. The trunk stations (Table 3) were optimized for a system with a carrier-to-composite triple beat ratio of 59 dB and carrier-to-noise ratio of 43 dB. To calculate the optimum output voltage for a trunk station, use Equation 8.

Where: Vspec = specified trunk station output level,
CNRspec = specified trunk carrier-to-noise ratio, and
CCTBspec = specified trunk carrier-to-composite triple beat ratio

3.3 Distortion Calculations

The station carrier-to-composite triple beat ratio, carrier-to-noise ratio, and noise figure are all determined by inserting Table 2 gain blocks into Figure 3 and calculating, on either a voltage or power basis, their distortion effect on station performance.

3.4 Maximum Trunk Reach

Maximum reach is defined as the maximum length in dB that trunk stations can be cascaded and still meet the trunk system requirements of 59 dB carrier-to-composite triple beat ratio and 43 dB carrier-to-noise ratio. To calculate maximum cascade, substitute trunk station performance for the Feedforward gain block performance in Equations 5, 6, 7, and 8.

Where: N = number of trunk stations in cascade

From Table 3, we conclude:

1. For the 31-32 dB Spaced Units. With a push-pull hybrid pre-amplifier and (FF1) output amplifier, trunk number 2 performs better than the 32 dB spaced trunk with two Feedforward stages. Power consumption in trunk station 2 is 11 watts less than trunk station 1.

2. For the 27 dB Spaced Units. The reach and power consumption of Model 4 is superior to that of 3. Model 4 requires 7.6 watts less.

No	Trunk Spacing dB	G1	G2	Maximum * Reach dB	Maximum* Cascade	Hybrid Power Watts	Vopt dBmV	Carrier-to-CTB dB	Carrier-to-Noise dB	Noise Figure dB
1	32	FF1	FF1	608	19	32.6	41.0	84.7	55.5	12.5
2	31	GB22	FF1	682	22	21.6	37.5	86.0	56.5	9.0
3	27	FF1	FF2	783	29	29.7	38.1	88.3	57.5	12.5
4	27	GB18	FF1	918	34	22.1	36.1	89.8	58.4	9.7
5	21	GB12	FF1	1050	50	21.1	34.5	93.0	59.9	12.6
6	22	GB18	GB18	704	21	12.5	29.4	89.3	58.1	8.3

*Using 43 dB CNR, 59 dB Composite Triple Beat Ratio

TABLE 3
Trunk Station Model Specifications

3.5 Power Consumption

The power consumption listed in Table 3 represents only the DC power consumed by G1 and G2.

3.6 Trunk Comparison

Table 3 summarizes performance of the trunk station models generated by installing Table 2 gain blocks into Table 3. All models are loaded to 450 MHz with 60 channels operating with a 7 dB output tilt.

Table 3 lists 21-22, 27, and 31-32 dB as three trunk spacing categories. Performance calculations assume that G1 operated at a distortion level 5 dB higher than normally encountered. We could, therefore, buffer the final trunk station performance calculation, since the input hybrid contributes to station distortion performance.

3. For the 21-22 dB Spaced Units. The dynamic range improvement of the FF1 gain block in Model 5 is reflected in the significantly improved reach.

From the Feedforward gain block modeling and performance data of the six trunk station models, C-COR proceeded to develop trunk station Models 2, 4, and 5. These stations are configured with an FF1 output gain block and a push-pull hybrid pre-amplifier of either 12, 18, or 22 dB to achieve spacings of 21, 27 and 31 dB.

4. Line Extenders

The line extender presents a different problem than the trunk because a gain of 34 dB is required. That gain spans the gap between +16 dBmV--the typical input level of the line extender--and the output capability limit of +50 dBmV of a Feedforward line extender. The 16 dBmV input level is mandated by the minimum signal level required on the feeder line; the 50 dBmV signal level is dictated by the non-linearity of Feedforward gain blocks operated above +46 dBmV out. Figure 4 illustrates a Feedforward line extender, and Table 4 lists performances of two models. One uses an FF1 output gain block; the other uses an FF2. For evaluation, both extenders were loaded to 450 MHz with 60 channels operating with a 7 dB output tilt. Extender distortion characteristics were calculated using the same methods for calculating trunk amplifier performance.

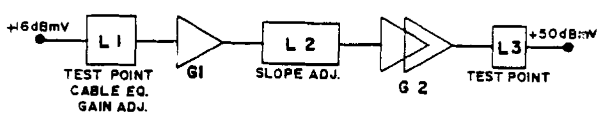


FIGURE 4
FEEDFORWARD LINE EXTENDER CONFIGURATION

From Table 4, we can conclude that Model 1 performed best, even though extender Models 1 and 2 both failed to produce the desired 34 dB extender spacing. G1 limited the distortion performance of Model 2 because of the low-gain characteristics of FF2. Although its power consumption is high, Model 1 or some similar design is the most desirable Feedforward line extender.

5. Conclusions

Answers to questions about Feedforward and its application to CATV distribution equipment follow.

1. The optimum Feedforward gain block configuration is FF1 (Figure 3).
2. The optimum Feedforward trunk station contains a standard push-pull hybrid as a pre-amplifier and an FF1 gain block as an output amplifier.
3. The optimum Feedforward gain block in line extenders is the same FF1 required for trunk application.

Model Number	Spacing dB	G1	G2	Output Level dBmV	Input Level dBmV	Carrier-to-CTB	Carrier-to-Noise	Noise Figure	Power
1	33	GB18	FF1	50	17	69.0	66.8	9.2	22.1
2	32	GB22	FF2	50	18	66.8	67.3	9.7	18.7

TABLE 4
Line Extender Model Specifications

References

[1]Meyer, Eschenbach and Edgerley, "A Wideband Feedforward Amplifier" IEEE Journal of Solid State Circuits, December 1974.

[2]Preschutti, Joseph P., "Feedforward Gain Block Performance Criteria" Engineering Report #695, C-COR Electronics, Inc., 1981

[3]Haney, Alan P., "Feedforward Trunk Gain Block Configuration" Engineering Report #704, C-COR Electronics, Inc., 1982.

STANDARDIZED RETURN LOSS MEASUREMENT OF CABLE TELEVISION DISTRIBUTION CONNECTORS

Bradford S. Kellar

RAYCHEM CORPORATION
Menlo Park, California

ABSTRACT

Return loss is a key parameter describing the electrical performance of cable television coaxial connectors. It is currently measured in a variety of different ways, making it difficult to compare manufacturer's specifications. This paper provides a standard approach which can consistently yield meaningful data.

The method is applied to measure the return loss of feed through connectors used for half inch distribution cable. This technique measures the effect of variations in center conductor and outer conductor diameters, connector length, and dielectric supports.

The measurement range is from 0dB to 50dB return loss. Experimental results, error analysis and fully dimensioned drawings of the special hardware are included. Transmission loss measurement and measurement of other connector types is described.

INTRODUCTION

As cable TV systems and local area networks using 75 ohm coaxial hardware extend to higher frequencies, problems with unwanted reflection of signals become more severe. System designers must rely on manufacturer's specifications to ensure adequate design margins, but in some cases these specs are based on measurements made with systems that contribute a high degree of uncertainty to the measurement. Worse yet, measurements made with "tuned" systems may make a product look better than it actually is. This paper will cover the theory of transmission line reflections, their measurement, uncertainty analysis, design of a fixture for connector reflection measurement and experimental results.

TRANSMISSION LINE THEORY

The chacteristic impedance Z_o of any lossless transmission line is given by

$$Z_o = \sqrt{\frac{L}{C}} \quad (1)$$

where L is the inductance in henrys per unit length and C is the capacitance in farads per unit length. In a coaxial transmission line,

$$L = \frac{\mu\mu_o}{2\pi} \cdot \ell n\left(\frac{b}{a}\right) \quad (2)$$

and

$$C = \frac{2\pi\varepsilon\varepsilon_o}{\ell n\left(\frac{b}{a}\right)} \quad (3)$$

where
ε = Relative Permitivity of the Dielectric
ε_o = Permitivity Constant = 8.85×10^{-12} farad/meter
μ = Relative Permeability of the Dielectric
μ_o = Permeability Constant 1.26×10^{-6} henry/meter
a = Diameter of Center Conductor
b = Inner Diameter of Outer Conductor

Incorporating equations (2) and (3) into equation (1) gives

$$Z_o = \sqrt{\frac{\mu\mu_o}{4\pi\varepsilon\varepsilon_o}} \cdot \ell n\left(\frac{b}{a}\right) \quad (4)$$

Since the dielectric usually has relative permeability = 1 (non-magnetic), we may write

$$Z_o = \frac{59.96}{\sqrt{\varepsilon}} \cdot \ell n\left(\frac{b}{a}\right) \quad (5)$$

Equation (5) is extremely useful in the design of coaxial connectors and transmission lines. It has been used extensively for the design of the standardized return loss fixture.

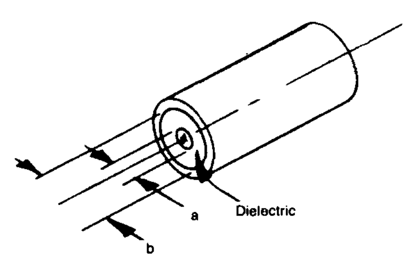


Figure 1
Coaxial Transmission Line

Cable TV systems have a characteristic impedance Z_o of 75 ohms, partly because this gives a convenient ratio of center conductor to outer conductor size, and partly because this is close to the optimum impedance for minimum signal attenuation. If a, b, or ε in Equation (5) are suddenly changed so that the impedance is no longer 75 ohms, a discontinuity is created which affects the performance of the transmission system.

Discontinuities

Any discontinuity in impedance along a transmission line causes power to be reflected back from the discontinuity.

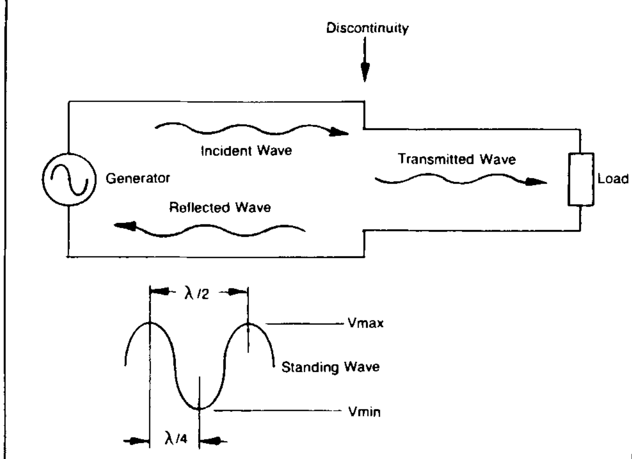


Figure 2
Effect of an Impedance Discontinuity

The magnitude of the reflected wave is expressed by the reflection coefficient ρ:

$$\text{Reflected Wave Voltage} = \rho \cdot \text{Incident Wave Voltage} \qquad (6)$$

where

$$\rho = \frac{Z_2 - Z_1}{Z_2 + Z_2} \qquad (7)$$

If $Z_2 = Z_1$, then ρ=0 and no wave is reflected. If Z_2 is an open circuit (impedance = infinite), then ρ=1 and the incident wave is totally reflected. Similarly, if Z_2 is a short circuit (impedance = 0), then ρ=-1 and the incident wave is again totally reflected but 180 degrees out of phase with the open circuit reflection. The logarithmic expression of ρ is known as return loss, defined as

$$\text{Return Loss} = -20 \cdot \text{LOG}_{10}|\rho| \qquad (8)$$

Return loss varies from 0dB (100 percent reflection to infinity (zero reflection), so the higher the return loss, the better the impedance match at the discontinuity.

The combination of incident wave traveling to the left and reflected wave traveling to the right forms a standing wave on the line. The amplitude of the alternating voltage varies with position along the line as shown in Figure 2, and the ratio of V_{max} to V_{min} is called the standing wave ratio, or SWR.

$$SWR = \frac{|V_{max}|}{|V_{min}|} \qquad (9)$$

The relationship between SWR and ρ is

$$SWR = \frac{1 + |\rho|}{1 - |\rho|} \qquad (10)$$

The impedance seen looking into a mismatched line varies with position as the SWR so that

$$Z_{max} = Z_1 \cdot SWR \qquad (11)$$

and

$$Z_{min} = Z_1 \div SWR \qquad (12)$$

If a cable TV system has poor SWR, the signal level will vary unpredictably along the line and the impedance that an amplifier sees on its output may vary substantially from the load it was designed to drive. Good system design practice, therefore, dictates low SWR connections.

Multiple Reflections

Systems with multiple reflections can be analyzed by representing each reflection as a polar quantity with magnitude ρ and phase shift θ. The magnitude of the overall reflection is the magnitude of the phasor sum of the individual reflections. A simple example is worked out in Figure 3, which illustrates the effect of a mismatched connector section inserted in a 75 ohm line at 250 MHz. As the frequency increases, the phase shift between ρ_1 and ρ_2 increases, increasing the overall reflection from this section. High frequency operation places more stringent requirements on connector design. (Incidently, computers are invaluable for keeping track of modelled systems with many reflections, and "sweeping" the model by varying λ to predict braodband performance.)

In reflection measurement set-ups, the effect of multiple reflections is to increase the uncertainty of the measurement. For example, if a device with ρ_1 = .05 is connected through an adapter with ρ_2 = .02, the measured reflection coefficient could vary between .03 and .07 since the phase difference between the two reflections is unknown (Figure 4). This is the principal problem with measurements where the connector being measured is seen through adapters and cable lengths which have reflections of their own that can exceed the reflection from the connector under test.

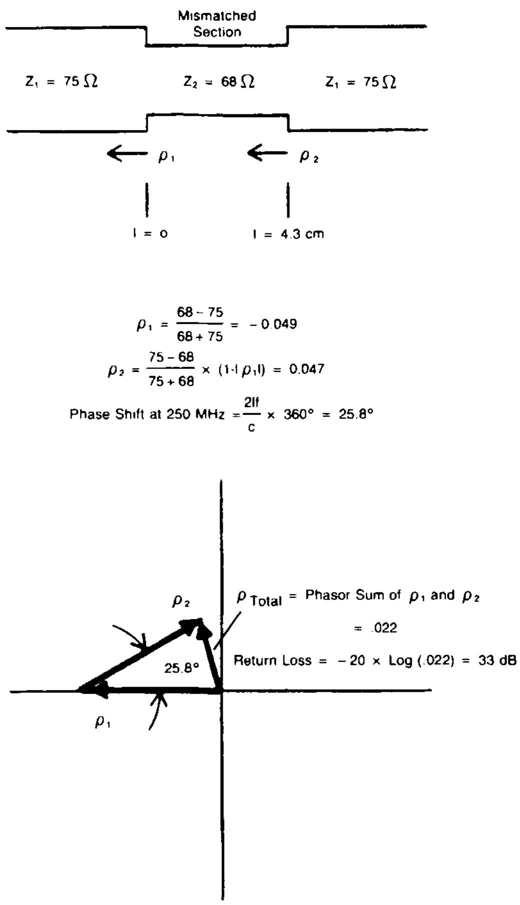


Figure 3
Mismatched Connector Example

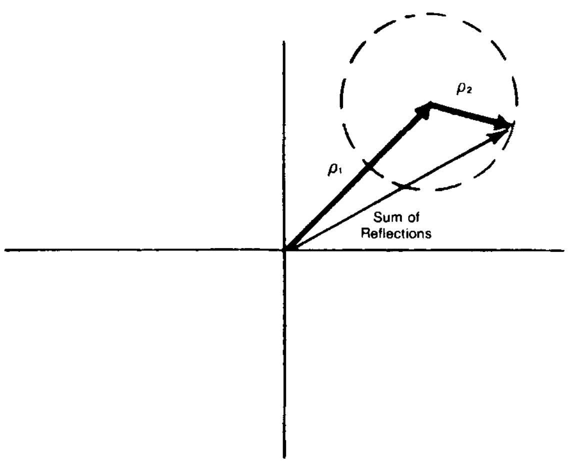


Figure 4
Uncertainty Due to Multiple Reflections

REFLECTION MEASUREMENT TECHNIQUES

All reflection measurement techniques require a means of producing test signals and measuring their amplitude accurately. We selected a Hewlett Packard 8754A Network Analyzer for this task. It includes a sweep generator to produce 4 MHz to 1300 MHz signals, two calibrated receiver channels and a logarthmic CRT display of signal amplitude. Several other manufacturers produce similar instruments. In addition to the Network Analyzer, some means of monitoring the reflections is needed.

Slotted Line

A slotted line is a transmission line section that has a narrow slot or groove running its length. A probe can be inserted in the slot and slid up and down the line until V_{max} and V_{min} (Figure 2) are found. Thus, SWR is measured directly, and ρ and return loss can be computed.

Slotted lines are very accurate, but they must be longer than a quarter wave length to ensure finding the peak and trough of the standing wave. At 50 MHz, the length must be greater than 1.5 meters, making precision fabrication difficult. That is why they are generally reserved for use above 500 MHz.

Directional Coupler

The directional coupler provides a means of separating the forward-traveling and backward-traveling waves through controlled interaction of parallel transmission lines (Figure 5a). Modern coaxial directional couplers are small and cover a broad frequency range, making them widely used. The signal labelled "R" is the coupled wave, which is proportional to the reflected wave. In use, a short circuit is placed on the test port (100 percent reflection = 0dB return loss) and "R" is measured. Then the short is removed and the device under test is connected. The drop in reflected signal expressed in dB's is the device's return loss. Since most network analyzers have a log display, return loss can be read directly.

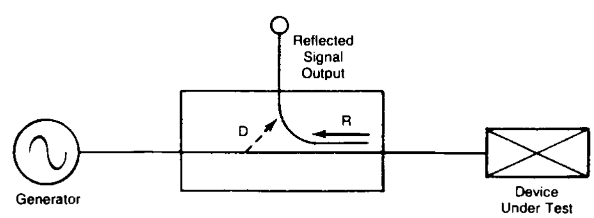


Figure 5a
Directional Coupler

The range and accuracy of small reflection measurements made with directional couplers is limited by the directivity of the coupler. The signal labelled "D" in Figure 5a is the unwanted leakage of the incident wave into the coupled line. This combines as phasor with "R" and directly affects measurement uncertainty, just as the adapter did in Figure 4. Most precision directional couplers have a directivity of 40dB, which is adequate for many applications. But if the return loss of the device under test has a return loss of 40dB, the measured return loss could vary between 34dB (both signals add) and infinity (both signals exactly cancel). Techniques such as short circuit/open circuit averaging can improve the accuracy, but generally require extra computation on a frequency-by-frequency basis.

VSWR Bridge

The VSWR bridge schematic is shown in Figure 5b.

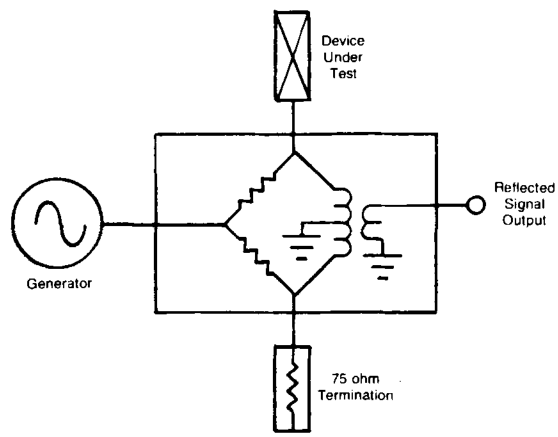


Figure 5b
VSWR Bridge

Through precision transformer winding, higher directivity than a directional coupler can be achieved. The Anzac model RB-3-75 is specified to have 48dB minimum directivity from 3 to 1,000 MHz. Since the higher directivity directly improves the measurement accuracy, this model was used for our tests.

The complete measurement set-up is shown in Figure 6. The HP 8502B Test Set is used to supply a reference leveling signal to the network analyzer. The HP 8750A Storage Normalizer provides a means of "remembering" the short circuit reflection calibration so that plotted calibration traces are unnecessary. The HP 11852A 75/50 Pad provides a means of adapting the 75 ohm bridge to the 50 ohm network analyzer input. Finally, there is the test fixture, the subject of the rest of this paper.

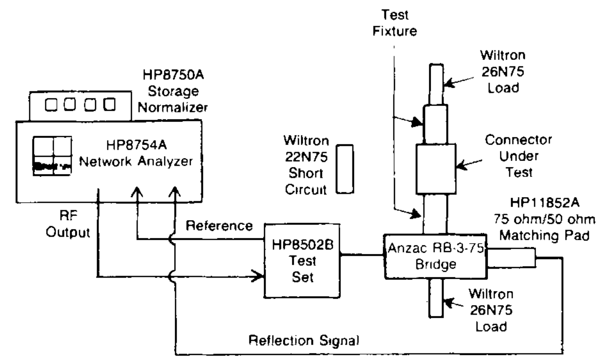


Figure 6
Test Equipment Setup

CABLE TV FEEDTHROUGH CONNECTOR MEASUREMENT

Problems

There are three major problems hindering accurate feedthrough connector measurement:

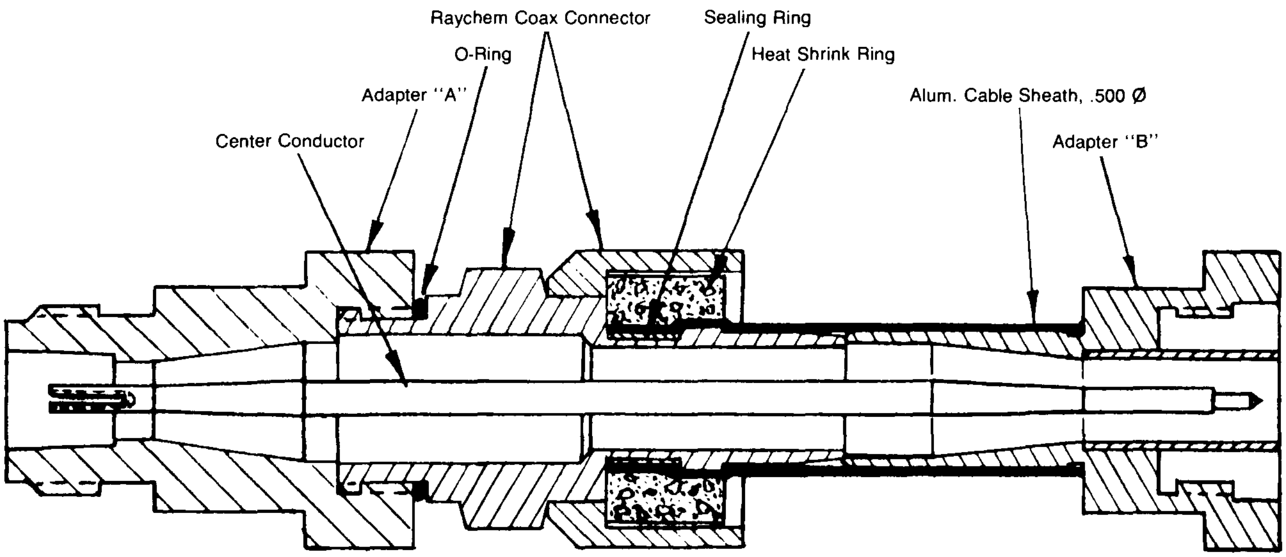
1. Connector reflection measurement assumes that no reflections come from beyond the connector (i.e., the load). "Homebrew" loads may have their own reflections which contribute uncertainty to the measurement. Furthermore, designs for these loads are not widely avaliable and have not been standardized by the industry.

2. Feedthrough connectors are designed to work with cable, but the introduction of cable into the measurement loop contributes uncertainty and non-repeatability to the measurement.

3. Precision lab test equipment usually uses Type N connectors. The adapters available to go from Type N to cable have refections of their own similar in magnitude to those from feedthrough connectors, making accurate measurement impossible.

Solutions

To solve the load problem, we decided to use a commercially available 75 ohm termination, the Wiltron 26N75. It has a specified return loss of >52dB to 1,000 MHz, and a male Type N connector. We then designed a fixture that (a) mates with the 75 ohm Type N connectors on the test port of the VSWR bridge and the load, (b) tapers to the dimensions of half inch cable TV coax with a .111 inch center conductor, (c) allows for mounting the feedthrough connector on the transmission line, and (d) maintains 75 ohm impedance throughout, per Equation 5. The center conductor is suspended only by its ends so that the impedance is not disturbed by supports or "beads". Figure 7 shows the fixture assembled with a Raychem feedthrough connector.

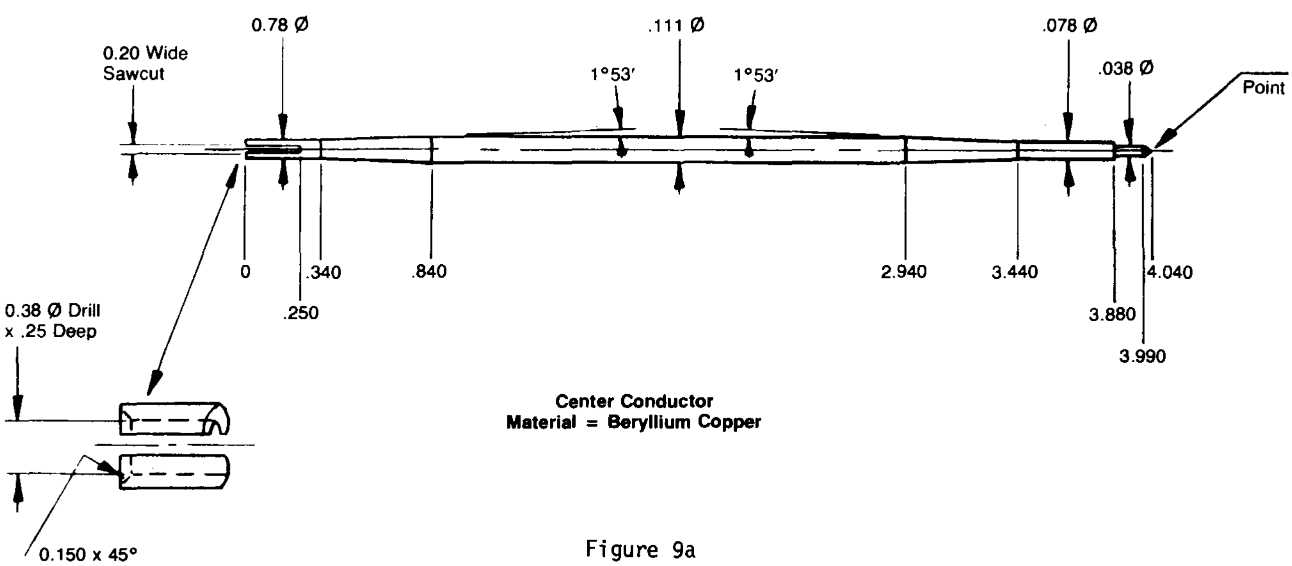


Assembly of Coaxial Connector Test Fixture

Figure 7

The center conductor must be held to tight tolerances for good performance. In particular, the line's impedance is sensitive to the center conductor's diameter, and the taper sections must begin and end on the same plane for center and outer conductor sections. Type N connectors have a specified "pin depth", that is distance between the shoulder or end of the center conductor and the reference plane in the outer conductor section. Therefore, the overall length of the fixture and center conductor must be accurately controlled.

Detailed drawings for the fixture are shown in Figure 9. The center conductor is made from beryllium copper so that the female pin fingers will be springy; the outer sections are brass. The connector is aligned with adapter "B" by a section of aluminum CATV outer conductor, which has been straightened to keep the components on axis. There is nothing tricky about this approach to connector measurement. It relies only on well known standards, formulas and commercially available products.



Center Conductor
Material = Beryllium Copper

Figure 9a

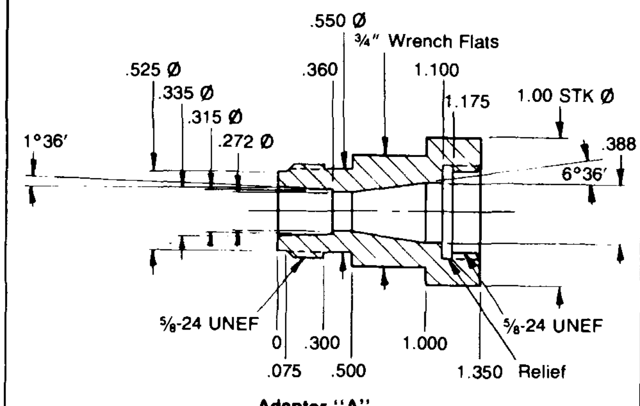


Figure 9b
Adapter "A"
Material = Brass

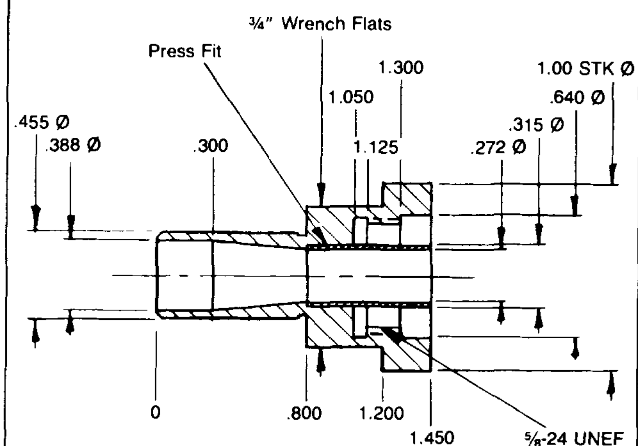
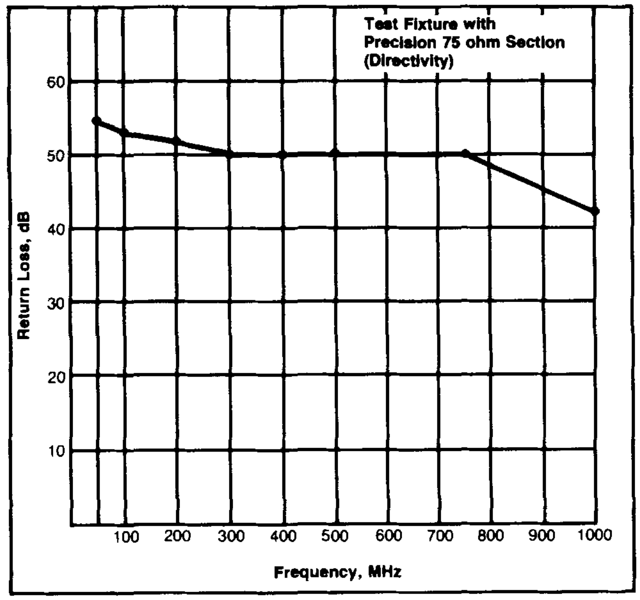


Figure 9c
Adapter "B"
Material = Brass

Evaluation of the test fixture was done with a dummy connector section designed to maintain exactly 75 ohm impedance. The return loss of the fixture is plotted in Figure 10 (<50dB to 750 MHz, 42dB @ 1,000 MHz). This is actually the combination of reflections from the fixture, the load and the directivity error signal, and comprises the effective directivity of the set-up. Since this effective directivity signal combines with the reflections from the connector under test with an unknown phase shift, it is the major contributor to the uncertainty of the measurement (Figure 4). Other lesser sources of error include the network analyzer's detector linearity ($\pm$0.5dB) and the repeatability of the connections.

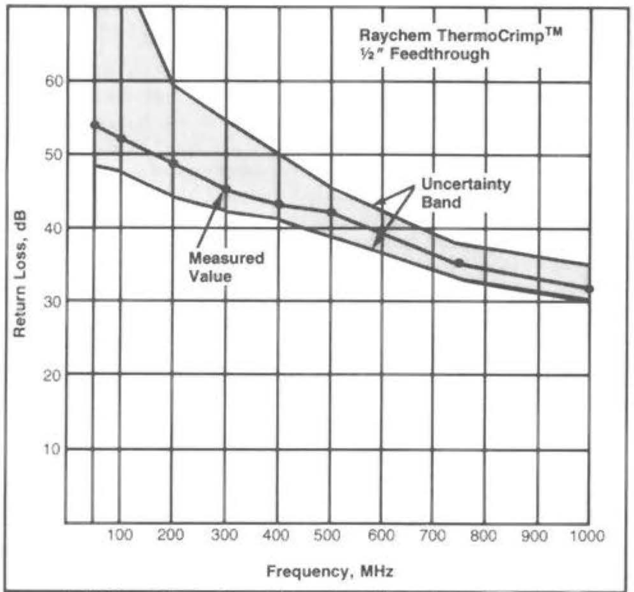


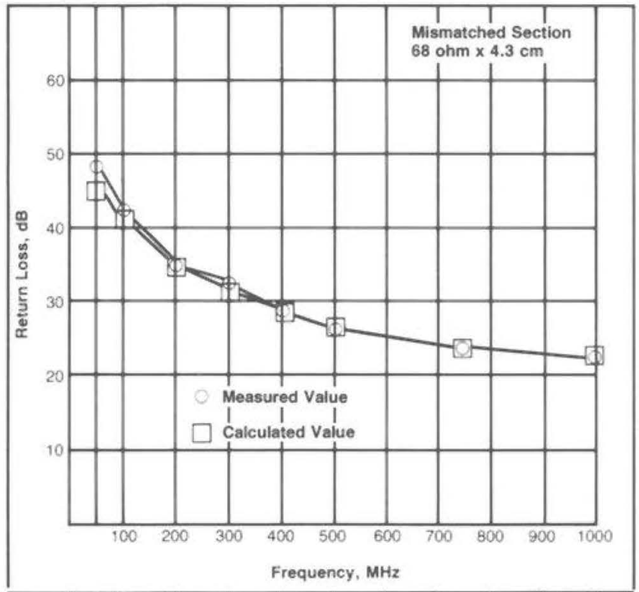
RESULTS

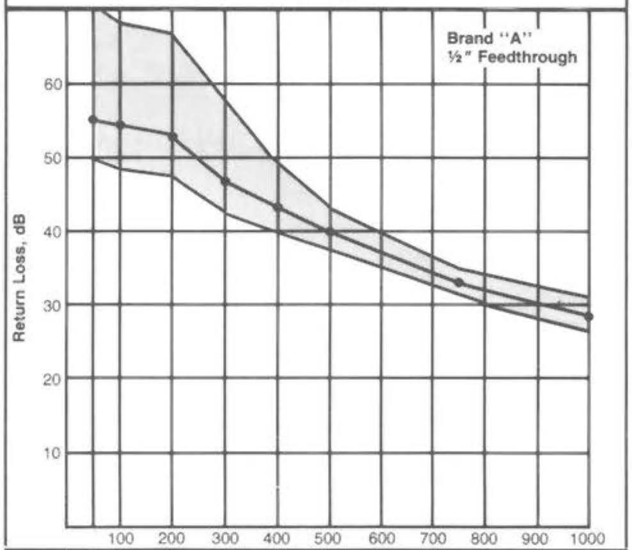
Eight samples each of the Raychem Thermo-Crimp connector, Brand "A" connector and Brand "B" connector were tested. The averages are plotted in figures 11, 12 and 13. The standard deviations were generally about 1.5dB, indicating fairly good repeatability. Brand "B", one of the most widely used connectors in the industry, clearly has inferior electrical performance compared to Raychem and Brand "A".

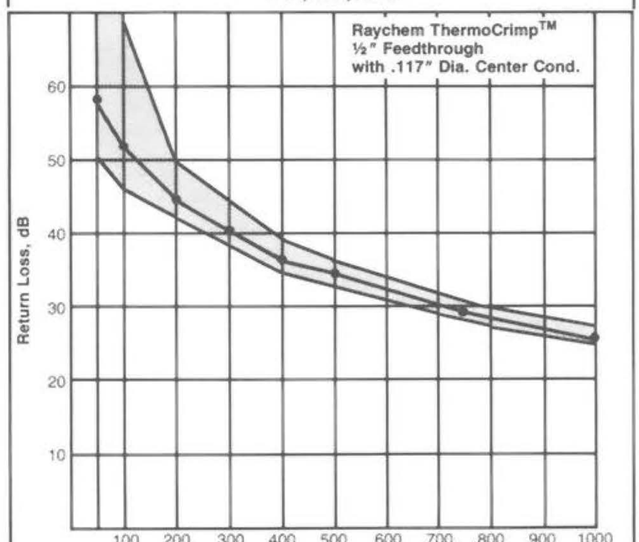
To illustrate the utility of the fixture, a mismatched connector with a uniform impedance of 68 ohms and length of 4.3cm was produced and measured. Figure 14 shows the predicted return loss based on a computer model and the measured return loss. The agreement between predicted and actual results indicates a reliable test.

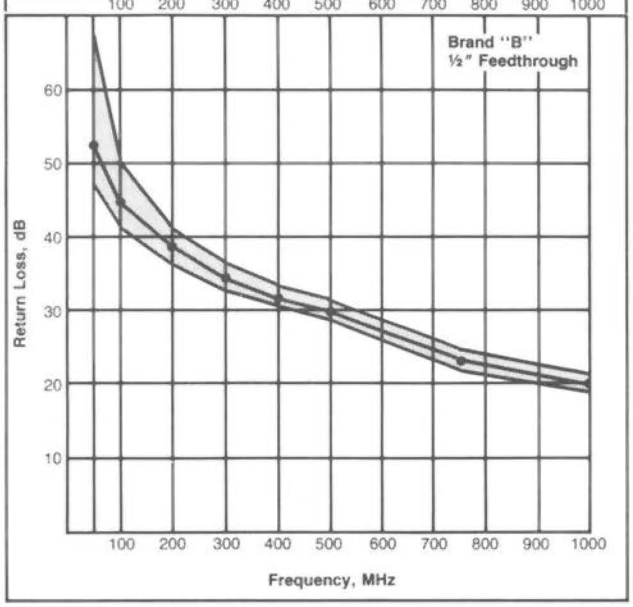
Not all half inch cable TV coax has the same diameter center conductor. The most commonly used cable has a center conductor diamter of .111 inches, but some older cables have a .099 inch center conductor and some recently introduced cable (Comm/Scope QR-500) has a .117 inch center conductor. Since the impedance of a coaxial line is sensitive to center conductor diamter, special center conductor sections of .099 inch and .117 inch diamter were designed for the test fixture. The measurement data for the Raychem connector with these sections, and for an alternate Raychem connector designed for a .099 inch center conductor, is shown in Figure 15. (A slight impedance mismatch is present because the tapered outer conductor sections were designed for a .111 inch center conductor and new sections were not made for this test.)

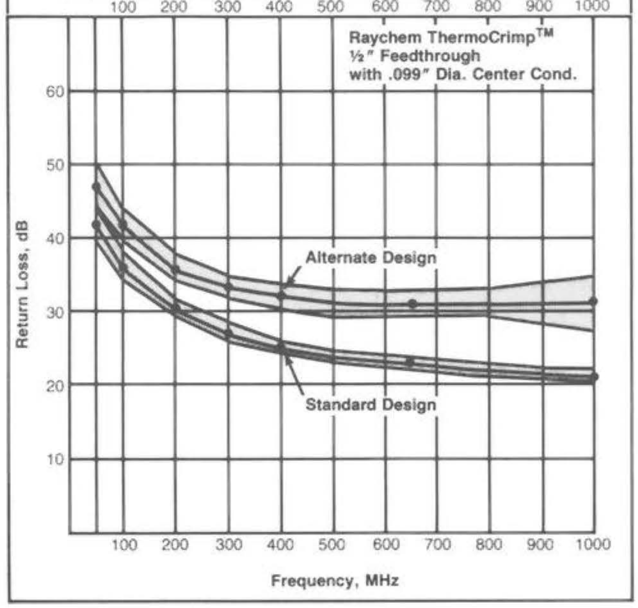

Raychem ThermoCrimp™
½″ Feedthrough
Uncertainty Band
Measured Value
Return Loss, dB
Frequency, MHz
10
20
30
40
50
60
100
200
300
400
500
600
700
800
900
1000


Mismatched Section
68 ohm x 4.3 cm
Measured Value
Calculated Value
Return Loss, dB
Frequency, MHz
10
20
30
40
50
60
100
200
300
400
500
600
700
800
900
1000


Brand "A"
½″ Feedthrough
Return Loss, dB
10
20
30
40
50
60
100
200
300
400
500
600
700
800
900
1000


Raychem ThermoCrimp™
½″ Feedthrough
with .117″ Dia. Center Cond.
Return Loss, dB
10
20
30
40
50
60
100
200
300
400
500
600
700
800
900
1000


Brand "B"
½″ Feedthrough
Return Loss, dB
Frequency, MHz
10
20
30
40
50
60
100
200
300
400
500
600
700
800
900
1000


Raychem ThermoCrimp™
½″ Feedthrough
with .099″ Dia. Center Cond.
Alternate Design
Standard Design
Return Loss, dB
Frequency, MHz
10
20
30
40
50
60
100
200
300
400
500
600
700
800
900
1000

OTHER TESTS

Insertion Loss

Loss of signal in connectors can be due to lossy dielectrics, resistive connections, or signal egress. It can be easily and accurately measured using the fixture by feeding the transmitted signal back to the network analyzer rather than terminating it in the load (Figure 16). None of the connectors measured exhibited insertion loss greater than .05dB, indicating that this is not a serious connector performance issue.

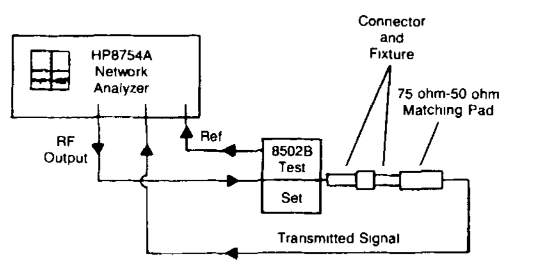


Figure 16
Insertion Loss Test Setup

Dielectrics

Most connectors use an insulating "bead" to center the center conductor. The effect of variations in raw material, molding processes, dimensions, etc., can be accurately assessed using the fixture described. Quality control of finished parts is also simplified.

Different Sizes and Types

The fixture design can be modified to allow testing of connectors for the different cable sizes. The tapers should remain gradual, pin depth controlled, and the fixture's performance verified using dummy sections.

Pin-type connectors and in-line splices can also be tested by this method. The center conductor will be split and it is suggested that the connector's pin be cut short and totally engulfed by the fixture's center conductor so that uniform impedance can be maintained. Again, fixture performance verification must be done to ensure accurate results.

CONCLUSIONS

A technique has been described which allows accurate and reproducible return loss measurement of cable TV connectors. The method is based on existing standards and as such, is available for all to use. It is useful for connector development and test, quality control, and evaluation of existing products on the market. Standardized test methods should help component manufacturers and system designers improve overall system performance, maintaining a healthy growth in the industry.

REFERENCES

1. I.S. Grant and W.R. Phillips, Electromagnetism Copywrite 1975, John Wiley and Sons Limited.
2. Samuel Y. Liao, Microwave Devices and Circuits Copywrite 1980, Prentice Hall, Inc.
3. Hewlett Packard Company, "Coaxial and Waveguide Catalog and Microwave Handbook", 1979-1980.
4. Wiltron Company, "Precision Swept Microwave Measurements", pp 42-53, Wiltron 1982 Catalog.

SYSTEM STABILITY AND CONTROL - A NEW AUTOMATIC CONTROL APPROACH

DEAN FREDRIKSEN

SCIENTIFIC-ATLANTA INCORPORATED

ABSTRACT

The need for automatic piloting of signals in a cable system is well established. As technology has advanced and the demand for cable services has grown, demands on the piloting system have become increasingly more complex. While new systems with extended performance have been designed, it is desireable that new equipment be compatable with old systems as well.

A new approach to automatic control systems utilizes the popular dual-pilot AGC and ASC scheme with some powerful new capabilities: plug-in filters for complete pilot frequency flexibility and plug-in servo cross-coupling networks. The combination of these two features greatly improves the agility and transient response of existing systems into which it may be substituted. In addition, it also permits complete flexibility with any pilot arrangement.

The theory of automatic gain and slope control (AGC and ASC) has been addressed in the literature. Some of the requirements for an AGC/ASC module are:

1. Temperature Stability: The primary cause of varying cable signal levels is environmental temperature change. The AGC/ASC module must maintain a fixed gain independent of temperature if it is to correct the changes induced by this variable.
2. Ease of set-up: The set-up procedure should be simple, quick, and be easily performed in the field. This saves time resulting in lower system installation and maintenance costs.
3. Isolation from trunk amplifier: The AGC/ASC module should have little or no effect on trunk amplifier performance except to control signal levels in the desired fashion.
4. Low power consumption: The less power consumed by the AGC/ASC, the more reliable the system is and the more power there is available for other system modules and accessories.
5. Transient stability: The transient response of a single station must be well-damped to prevent the build-up of large low-frequency fluctuations in a long cascade.

While all of these factors are important, one of the most difficult design problems is posed by transient stability. The innocuous, well-behaved response of an AGC/ASC amplifier to induced transients can be greatly misleading in a cascade of these same amplifiers. This paper will consider stability problems in a dual-pilot AGC/ASC system and show how they can be virtually eliminated in existing and future systems.

A notable cause for stability problems is the placement of the pilot channels at frequencies far removed from the slope pivot frequency in the trunk amplifier. Because of demands for higher frequency capabilities (more channels) the high pilot carrier is typically pushed further up the frequency spectrum to gain adequate sensing and leveling of these higher ranges.

In some systems the high pilot and low pilot carriers are on opposite sides of the slope pivot point. If the low pilot controls amplifier slope and the high pilot controls amplifier gain, then as the slope control is varied, the high and low pilot levels adjust in different directions. The variance of the high pilot to adjustments of the slope control voltage is a function of the frequency separation from the pivot point - the greater the distance the greater the change in high pilot level for the same change in slope control voltage. Placing the high pilot near the high end of the frequency spectrum (where it should be for good gain sensitivity) creates a system where small changes in the slope control voltage produce a large system closed loop correction at the high frequency pilot. At some frequency spacing this eventually leads to unstable dynamic performance. By coupling some slope control voltage into the gain control circuit, the slope pivot point can effectively be moved to the high pilot point or above, resulting in a system with better dynamic performance. Likewise, by making the amplifier slope respond to gain control voltage, interactions from high pilot to low pilot can be reduced. In any system, if flexibility with respect to pilot frequency and band splits is desired, cross-coupling improves the slope and gain control interactions.

A Scientific-Atlanta Trunk station was set up (see Figure 1) using a 400 MHz trunk amplifier and automatic control module (ACM). Taps were used on the trunk input and output to simultaneously sample the input and output RF levels. Two Hewlett Packard 8558B spectrum analyzers were used as tuneable detectors allowing individual monitoring of the input and output high and low pilot carriers. HP 8640B signal generators were used to generate the 77.25 MHz (low) and 379.25 MHz (high) modulated pilots. A Spectral Dynamics SD375 dynamic analyzer was used to obtain the transfer function (both magnitude and phase) of the trunk/ACM pair. From this information one can readily show instabilities in the servo loop response due to the imprudent selection of pilot frequencies with respect to the slope pivot frequency, which is 200 MHz. This combination of pilots has not been recommended in the past and is chosen to illustrate a potentially unstable servo response. Four particularly important transfer functions were measured:

1. The response of the high pilot output to high pilot input modulation (T11).
2. The response of the high pilot output to low pilot input modulation (T12).
3. The response of the low pilot output to high pilot input modulation (T21).
4. The response of the low pilot output to low pilot input modulation (T22).

The transfer function shows the magnitude (dB) and phase (degrees) of the signal output as a function of the signal input. Since the ACM uses peak detectors, its sensing is relatively unresponsive to low-frequency video components. There are however, other low-frequency signals present in a cable system as noise . To improve immunity to low-frequency noise, a low servo loop bandwidth is desired. There is, conversely, a practical limit to how low the bandwidth can be set. Making it too low will make the system difficult to set up because it results in a long system response time. In this system, the cross-over frequencies are approximately .5 Hz (high) and .7 Hz (low). Ideally, the transfer function should show unity gain (or less for cross-coupling coefficients) at higher frequencies and very high attenuation of low frequency inputs. This means that low frequency disturbances will be greatly suppressed. The preferred frequency response is well-damped, with no peaking or ringing in the transfer function.

Transfer function data was taken to 200 Hz. However, no significant perturbations in the response were noted in any case beyond 10 Hz (see Figure 2). Therefore, for the sake of brevity subsequent figures shall include only transfer functions to a maximum modulation frequency of 20 Hz. Figure 3 shows the response for the worst case of T12.

The Scientific-Atlanta Automatic Control Module (ACM) allows substitution of plug-in cross-coupling networks for different combinations of pilot carriers and the appropriate network was plugged into the ACM. (New Scientific-Atlanta Trunk amplifiers have the cross-coupling designed into them). Figure 4 shows the station response (T12) with cross-coupling. Figure 4 shows how the inclusion of cross-coupling improves the control system stability. Notice how the peak shown in Figure 3 has been greatly reduced. The inclusion of cross-coupling yields even greater stability improvements in long cascades, as will be shown shortly.

It would be meaningful to predict beforehand what the response of a cascade of many amplifiers would be. This can be accomplished by assuming a modulated source and multiplying it by the transfer function measured previously. The output would then be substituted as the source for the next trunk station and be multiplied by the transfer function again, until the desired cascade length is reached. A computer program was written to perform this multiplication and the results are given in graphical form. Figure 5 shows the predicted response of twenty cascaded trunk stations before, and Figure 6 shows the results after cross-coupling the slope and gain controls.

The system in Figure 5 is very unstable and would be unuseable. It shows a high degree of peaking in the vicinity of 2 Hz which would manifest itself in wild level variations at low frequencies. The system would be driven beyond its AGC and ASC ranges and may be very difficult to measure. Small deviations of the input level would cause the dynamic range of the AGC and ASC-controlled amplifiers to be exceeded somewhere down the cascade. On the other hand, the cross-coupling added in Figure 6 predicts a stable, well-behaved cascade of amplifiers.

"The proof of the pudding is in the tasting" and happily, the test results bear out the mathmematical predictions. When the test set up of Figure 1 was extended to include 20 cascaded amplifiers, the results were as follows:

Figure 7: This graph shows the measured results of cascading 20 identical amplifiers with the characteristics given in Figure 3.

Figure 8: The measured results of 20 cascaded amplifiers with cross-coupling are given here. Note the dramatic improvement in system stability. There has been a reduction of system peaking by more than 72dB!

CONCLUSION

The use of cross-coupling provides flexibility in the selection of pilot carrier frequencies. With plug-in filters and compensation networks, a potentially unstable pilot combination can usually be salvaged. Systems can be upgraded without replacing the AGC/ASC modules. Only the plug-in filters and compensation network need be changed - a modification that could be done in the field resulting in cost savings for system upgrades. Systems with unusual pilot frequency requirements can now be handled and performance of existing systems can be improved through the use of higher pilot frequencies.

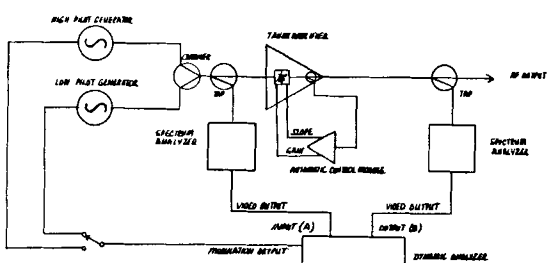


FIGURE 1 - TRANSFER FUNCTION TEST SET-UP

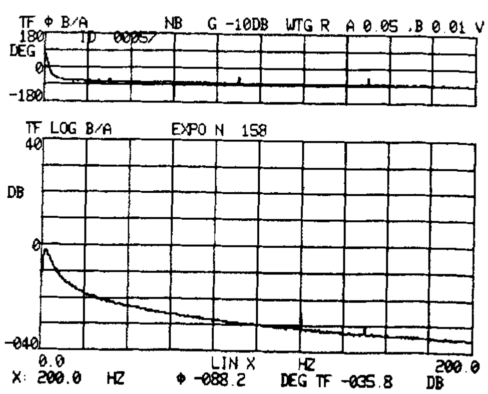


Figure 2

Transfer function for worst case of T12 (taken to 200 Hz). Graph shows trunk amplifier output (B) of high pilot (379 MHz) for modulation of low pilot (77 MHz) input (A) vs. frequency. Single amplifier, no cross-coupling.

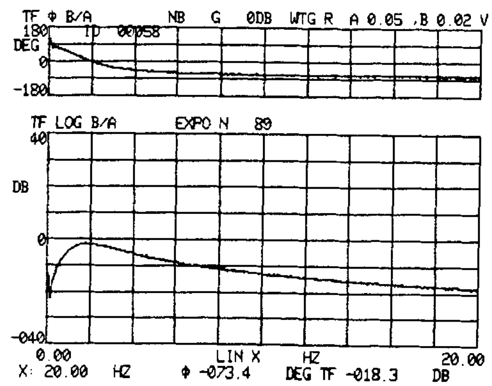


Figure 3

Transfer function for T12 (taken to 20 Hz). Graph shows trunk amplifier output (B) of high pilot for modulation of low pilot input (A) vs. frequency. Single amplifier, no cross-coupling.

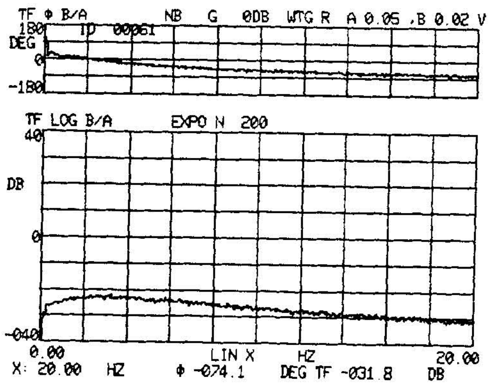


Figure 4

Transfer function for T12 showing trunk amplifier output (B) of high pilot for modulation of low pilot (A) vs. frequency. Single amplifier with plug-in cross-coupling.

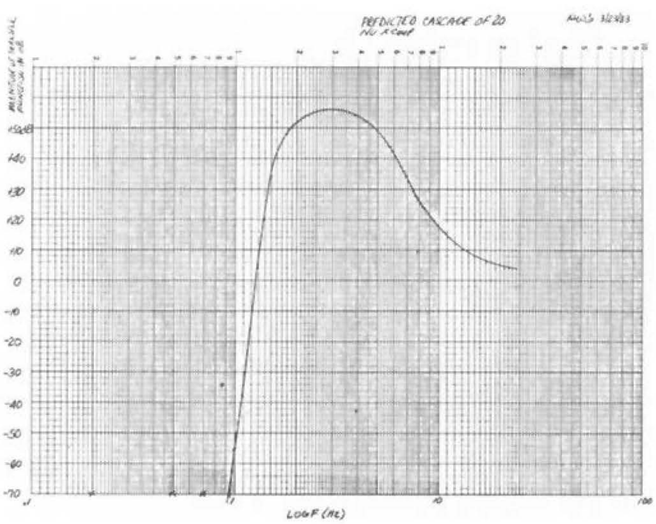


Figure 5

Computer-perdicted transfer function of T12 for a cascade of 20, based on measurement of single amplifier. Graph shows trunk amplifier cascade output (B) of high pilot for modulation of low pilot (A) vs. frequency. Cascade of 20 amplifiers, no cross-coupling.

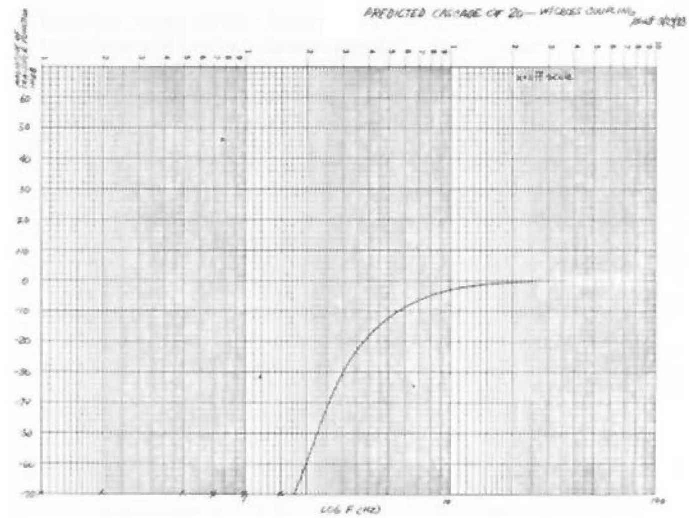


Figure 6

Computer-predicted transfer function of T12 for a cascade of 20, based on measurement of a single amplifier. Graph shows trunk amplifier cascade output (B) of high pilot for modulation of low pilot (A) vs. frequency. Cascade of 20 amplifiers, with cross-coupling.

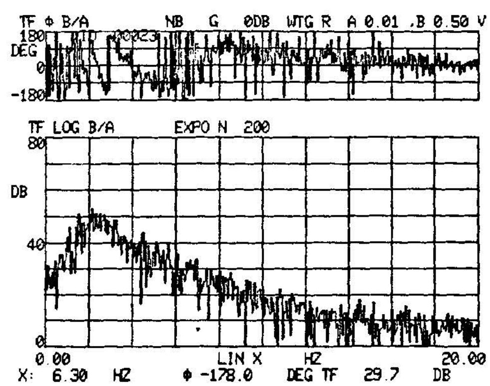


Figure 7

Transfer function of T12 for a cascade of 20 amplifiers. Graph shows trunk amplifier cascade output (B) of high pilot for modulation of low pilot (A) vs. frequency. Cascade of 20 amplifiers, no cross-coupling.

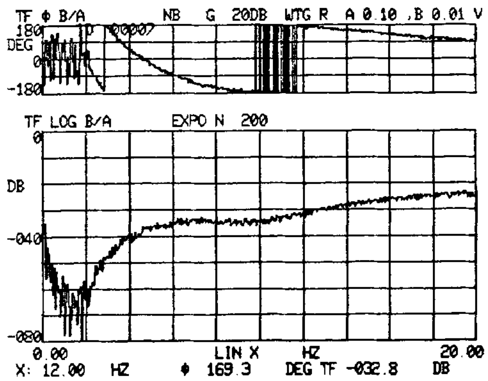


Figure 8

Transfer function of T12 for a cascade of 20 amplifiers. Graph shows trunk amplifier cascade output (B) of high pilot for modulation of low pilot (A) vs. Frequency. Cascade of 20 amplifiers, with cross-coupling.

ACKNOWLEDGEMENTS

I wish to thank Dr. Lorimer Clayton for writing the transfer function multiplication program and Mr. Rezin Pidgeon for his technical and editorial guidance.

BIBLIOGRAPHY

1. Chisolm, Eric W., "Considerations on the Application of AGC/ASC Amplifiers in CATV Systems", IEEE Transactions on Cable Television, Vol. CATV-1, No. 1, October 1976.

2. Kreyszig, Erwin, Advanced Engineering Mathematics, Third Edition, John Wiley and Sons, Inc., New York, 1972, pps. 102 - 187.

3. Millman, Jacob and Halkias, Christos, Integrated Electronics: Analog and Digital Circuits and Systems, McGraw-Hill Book Company, New York, 1972, pps. 408 - 477.

4. Truxal, John G., Control System Synthesis, McGraw-Hill Book Company, New York, 1955, pps 334 - 360.

5. Vistor, W.K. and Brockman, M.H., "The Application of Linear Servo Theory to the Design of AGC Loops", Proceedings of the IRE, Volume 48, February 1960, pps. 234 - 238.

THE CASE AGAINST OFF-PREMISES CONVERTERS

I. Switzer - Engineering Consultant

Media General Cable of Fairfax County, Virginia
14650 Lee Road
Chantilly, Virginia 22021
(703) 378-8400

ABSTRACT

Off-Premises converters are being developed to solve problems that are better solved by subscriber ownership of cable television terminal equipment. Cable systems should move toward less equipment, located in the harsh external environment, being owned by the cable system, rather than more. The principal barrier to subscriber ownership is the lack of low cost "fool-proof" video/audio coding technology. This technology is in prospect and should be encouraged as a necessary basis for subscriber ownership of terminal equipment. Subscribers will benefit from a competitive market in terminal equipment, as in telephone equipment.

PERCEIVED PROBLEMS

The present interest in off-premises converters appears to have arisen from several concerns of cable system operators:-

- The high cost of Pay-TV control - particularly the high cost of secure descramblers.
- The high risk of "security compromise", i.e. the risk that theft of service will become rampant.
- The high cost of home terminal "asset control", i.e. the risk that subscriber terminal equipment (converter/descramblers) will not be recovered from subscribers' homes.
- The high cost of home subscriber terminal maintenance.

Cable system operators see off-premises converters as a cost effective solution to these problems:-

- Off-premises converters do not need descramblers since unauthorized services do not enter the home. This saves the cost of descramblers.
- High-value services are contained within the trunks and do not enter subscribers' homes where they might be subject to "theft".
- Only a low-cost, low value, remote control unit is placed in subscribers' homes.
- Most terminal equipment is outside subscribers' homes where maintenance is presumed to be easier and cheaper.

I recognize and acknowledge the problems but I disagree with the off-premises converter as a desirable solution to the problems. I am opposed to "off-premises" systems of this kind for several reasons:-

- They place complex equipment in a hostile outside environment with consequent design and operating problems.
- They are inevitably more costly than the present subscriber terminal equipment.
- Their placement outside the home creates new maintenance access problems. The problem of maintaining additional equipment outside the home in hard to get to kiosks and/or pole mounted housings should not be underestimated. There is also a problem in providing power for these outside devices.
- The required outside housings are bulky and create an aesthetic problem.
- There is a serious problem with multiset households. The systems being demonstrated require a separate drop line for each TV set in the home. There will no doubt be multiplexing of multiple outside converters and remote control links onto a single drop cable, but the requirement for multiple outside terminal equipment for multi-set households aggravates the previously cited problems.
- These systems do nothing to solve the problem of the costly functional redundancy inherent in duplicating the tuning function in both the cable system and the subscriber's TV receiver.

It is my view, however, that all of these problems would be solved by subscriber ownership of terminal equipment. The issue is the "dividing line" between the distribution system and the subscriber. Many engineers believe that investment in terminal equipment should be increased and that the "terminal" function should be more extensively integrated with the distribution system. They want to bring the program selection function out of the home and integrate it with the distribution system. I want to rid myself completely of "terminal" functions and make the subscriber responsible for the provision, maintenance and operation of terminal equipment. I don't want to buy, own, maintain and keep track of subscriber terminal equipment. I believe that the public would be best served by technology which allows individual subscriber ownership of this terminal equipment. The cable systems business is be best served by technology which allows us to conserve these capital and operating resources and use them for additional distribution plant and subscriber services.

THE SHIFTING "DIVIDING LINE"

We are seeing at this time a "tug-of-war" between receiver manufacturers and cable systems as to where the dividing line of equipment ownership would be. Receiver manufacturers would like maximum ownership by subscribers, thus maximizing their own participation in the business of supplying this equipment. Cable system operators want the technical flexibility and the increased profit potential of supplying as much of the subscriber terminal equipment as possible. For this, and the other reasons I have cited, there is a growing interest among cable system operators in moving the subscriber terminal equipment outside the home so as to maintain better control of it.

There obviously has to be a change of interface. I don't think that anyone in the cable industry is willing yet to completely standardize the channeling of cable systems. The matter of cable tuning can best be handled by moving the interface from the subscriber tuner input to the demodulator output. Cable subscribers are now able to buy video/audio "monitors". Video/audio interfaces can be readily standardized. The standard input to the subscriber owned equipment should now be baseband composite video (with baseband audio) with RGB optional. Appropriate tuner/demodulators could be supplied by the cable system or could be purchased by the subscriber. Manufacturers could decide whether and which tuners they wish to make and sell. "Off-air" tuners could be offered, as well as tuners for the more popular cable channeling ranges and plans. Tuners might optionally offer RGB outputs as well as standard composite video baseband. New TV broadcast services with stereo audio would require new demodulators with baseband stereo audio output. Further extensions of cable system operating bandwidth would obsolete earlier tuners, but it would be cheaper for a subscriber to replace his tuner with a newer model than to replace the whole TV set just because of an inadequacy in tuning range. These tuners could alternatively be provided by the cable system who could themselves purchase these units from various receiver manufacturers or from specialized manufacturers. Manufacturers of video devices such as VCR's, video disc systems, video games, home computers, etc. would also benefit since they could then feed the user's video/audio monitor directly, without an RF interface.

"Component" TV sets with separate "tuners" and "monitors" are now available from several manufacturers.

THE PAY-TV CONTROL PROBLEM

Subscriber ownership of terminal equipment requires a major improvement in video and audio security. We must develop a standardized coding and addressing system for controlling premium TV services. This would allow all the tuning and premium control functions to be owned by the subscriber as part the subscriber's own television receiver, while full control over premium services is retained by the cable system.

Let us distinguish between "scrambling" and "coding" of television signals. "Scrambling" merely modifies the signals so they cannot be received and/or displayed on a conventional TV receiver. Sync' suppression is a common form of scrambling. Video polarity inversion, FM transmission and "jamming signals" are other forms of scrambling. Knowledge of the technique allows "descrambling". You can build a descrambler that will work if you know the scrambling technique. Some systems use very sophisticated scrambling techniques that required more sophisticated descramblers, reducing considerably the risk that average individuals will reproduce or otherwise acquire the required descrambler. There is still very little protection from determined efforts to breach such a security system on a large scale. Another deficiency of such systems is the fact that mere possession of a descrambler often defeats the system. Some systems can address such "lost" descramblers "OFF", receiving some degree of protection, but there are still significant economic problems associated with the loss of descrambling equipment and the theft of services.

"Coding" modifies the signal in such a way that decoding needs both knowledge of the technique and the particular code or cypher that has been used to encode the signal. The technique is analogous to the encryption of high security message traffic. The coding techniques are usually digital but they do not always require digitizing the signal. Coding techniques appeal because they would allow the subscriber to own the decoding equipment. Nationally standardized decoders could be built into new TV sets. We can then sell the subscriber the decoding equipment because it won't work until we sell him the code required to make the box work right. The code would be unique to a particular program service and a particular subscriber decoder. We can change the code every day, every week, every month or for every program. The code supplied to the subscriber to operate the box won't work in his neighbor's box for the same program, nor will knowledge of the codes supplied to a large number of subscribers provide a decoding "key".

A national standard is probably an unrealistic expectation. Interim company-wide or regional standards can be implemented by the "component" approach. Suitable tuner/demodulator/decoder "components" can be made available for whatever channeling and coding standard a particular cable system chooses to use. Video/Audio monitor componenets would continue to have a high degree of national standardization, although cable systems might choose to introduce improved color coding technology. In this case the tuner/demodulator/decoder module would have RGB outputs for monitors having this capability and would include color re-encoding to standard NTSC for those that don't.

"Addressing" has been shown to be a very useful adjunct in subscriber terminal equipment. A nationally standardized addressing scheme would also be desirable, but subject to the same practicality problems that I have discussed for video/audio coding.

SOME CODING TECHNIQUES

Several coding systems have been developed and demonstrated. One such system inverts the video polarity of the signal in a pseudo-random line sequence, i.e. the number of scan lines in each polarity group is changed in a pseudo-random way. I was impressed with the effectiveness of coding as an alternative to scrambling, but I was not enthusiastic about alternating video polarity as a means of concealing the signal. I believe that there are problems in matching the "positive" and "negative" video channels in the decoder. The gain of the video polarity inverter must be closely controlled and problems of transmission linearity arise.

I have also seen demonstrations of "line shuffling". I believe that this technique is the most promising and very worthy of consideration as a national standard. Conventional video is read into a digital frame store in regular scan sequence. The lines are read out for transmission in a pseudo-random sequence. A similar store at the decoder reads in the lines as received and then, knowing the code, reads them out of the store in the proper sequence for display. The earliest demonstrations that I saw (by Anderson Labs, a manufacturer of digital frame stores), used a full frame digital store (525 lines of storage). This is obviously a very expensive system since decoding requires a similar store. I believe that a system using as few as eight lines of storage would be adequate. I believe that the prospect for developing low cost consumer versions of such a decoder using either digital or analog storage is very good. "Professional users" could use digital storage for decoding. "Consumer users" could use lower cost CCD's or similar analog video storage devices.

I consider "line shuffling" to be an ideal video encoding technique. The advent of low cost digital video signal processing, now being introduced by some TV receiver manufacturers, will make "line shuffling" a practical video coding technique for consumer level application.

It is now quite practical to handle audio in digitized form, using available encrypting systems. I believe that a suitable digital system can be made to fit within the available aural subcarrier bandwidth without causing impairment of the video transmission. Digital audio transmission will benefit from the current introduction of digital audio disc systems. This makes low cost digital audio "chips" available.

The cable system operating industry must go to "coding" instead of "scrambling". Ideally we would decide on a particular coding system as a national standard so that the decoders can be built into TV sets and so that low cost decoders can be made available to subscribers on a competitive basis. A nationally standardized addressing system is also important. I believe that subscriber terminal equipment is best made and distributed by the consumer electronics industry. Cable subscribers would enjoy a substantial benefit from a competitive market in subscriber terminal equipment. The beneficial experience with subscriber ownership of telephone terminal equipment has shown that a competitive market-place reduces costs to the user, increases variety and utility of equipment, and creates a wider opportunity for manufacturing and distribution entrepreneurship.

THE CHANGING CABLE-SATELLITE CONNECTION

KARL POIRIER

TRIPLE CROWN ELECTRONICS INC.

The delivery of television service via satellite now faces the most dramatic changes in many years. The introduction, during the last 12 months of three totally new delivery systems, and their implementation in the U.S. will affect all CATV operators. The activation of the first full encryption service, the first KU band Pay television, and the licencing of DBS, present an entirely new set of technical problem to the operator. We will examine the effect of the changes through their implementation in Canada. The lessons learned may help the transition facing the American CATV operator, when these new technologies are instituted in the U.S.

INTRODUCTION

The distribution of Pay TV via Satellite is now a well established technology. In the last few years, the system has evolved from the first telecom supplied TVRO's to the present company owned uplinks. From the first days of parametric amplifiers and 10m TVRO's to today, when a TVRO system is within the reach of the smallest cable operator. It is a well proven fact, that when the technology expands, the price and complexity comes down. This development is not always smooth, and in fact, some major obstacles have, and will lie in the way. Before we, as cable operators look back, smile and say "Well, we did it", perhaps we should peek around the next corner. Three major developments of the last 12 months will dramatically affect the equipment market and the cable operator. The changes which will result from these advances, and the interface engineering problems along the way, will lead to a very different cable satellite system in the near future. This process has begun, as two of these developments are already on line and operating in Canada, and the third is in progress in the U.S.A.

THREE MAJOR SATELLITE DEVELOPMENTS

- In May 1982, Canadian Satellite Communications Inc. (Cancom) began the delivery to cable and LPTV system of <u>fully encrypted television</u>.

- In September 1982, the Satellite Television Corporation (STC) was authorized by the FCC to construct a DBS system to cover the U.S.A. (12.2-12.7 GHz).

- In February 1983, Pay TV came to Canada via ANIK C in the KU (11.7 - 12.2GHz band).

The recent announcement by HBO that they too, will be encrypting signals, means that the same lessons learned with CSC Canada will soon apply to the U.S. The success of Pay TV delivery via KU band, and the benefits in areas such as interference, will push the US towards this type of delivery. DBS, for the first time, takes satellite communications into the area of mass consumer production.

THE TRANSITION TO ENCRYPTION

Programming in Canada is much more tightly regulated than in the U.S. The regulations are designed to control outside cultural influences, as well as to protect the local broadcaster from unfair competition. The geography however, presents a problem in that the regulations are only enforceable in the more densely populated areas. By 1981, a very embarrassing situation had developed. While cable operators in major cities were trying to get approvals to receive everyday U.S. network programming, every pothole community in the northland had a dish, and was distributing HBO illegally. Efforts to stop this activity were met with an unanswerable argument: there was nothing else available. The government decided to license the delivery of four Canadian independent stations, to which these communities could subscribe. There were, however, some initial constraints applied to the system.

FIRST : Canadian law holds strong rights for a local broadcaster. Any other service must delete all simultaneous programming. Many communities had a local CTV network affiliate, and one of the uplinked independants was a network affiliate.

SECOND : Several sports associations argued that a blacked out game in Toronto could be received on the Vancouver up-link by a Toronto tavern.

THIRD : Subscribing communities paid for the service on a monthly, per customer base. Collecting an overdue account from an operator on the Beauford Sea is only slightly easier than from a customer in Afghanistan.

THE ANSWER : Addressable encryption. CSC chose a system comprised of Multi Mode Encryption, Digitized Audio, and Computer control of Decoders.

The Problems

The initial fire up problems were quite severe and could be categorized into three distinct items:

A) The quality of the TVRO equipment

B) The new factors introduced into the signal

C) The technical operation of the link

The TVRO systems in most communities to be served by CSC had been designed to provide minimum acceptable picture quality. 10' antennas and spherical mesh antennas were common, and receive equipment was very often consumer grade or surplus gear. G/Ts of 17.5 to 18.5, and C/Ns of 8 were very common. Most systems did not even have proper accommodation, and were installed by people with little or no technical expertise.

The encryption manufacturer had specified a minimum G/T of 20.4 and a minimum C/N of 11dB. The difficulties in trying to explain why a system delivered good pictures from Satcom, and poor pictures in the encrypt/decrypt mode, to untrained operators were enormous. The adamant operator view of "it was OK before, so it must be the scrambling", was a major problem. In reality, any system which delivered cable quality pictures without the use of limited bandwidth or threshold extention was probably suitable for encrypted traffic. The use of low quality antenna systems and low cost receivers (PLL) etc. is not confined to the Canadian North. Indeed many small American cable operations have cut a few corners in this way. It is safe to assume that the problems will occur in much the same way when HBO and others begin encryption.

The encryption system introduced several new factors to satellite transmission. Most significant among these were sync suppression/restoration, and high rate data traffic. These two factors caused significant difficulties for receive equipment in the field. In order to handle this signal, the typical receiver required the following changes:

All sync handling circuitry had to be disabled. Any residual clamping action would act on the data streams rather than on the non existant sync. In addition, the lack of sync makes level setup quite confusing.

Increased video headroom and response were required to handle the high data rate. The combination of pre-emphasis, and data overshoot, often makes the data the highest peak to peak content of the signal. A typical example of what may happen in these cases is shown in Fig. 1 and Fig. 2. Fig. 1 shows a data burst riding in a sync location, and being affected by a sync clamping circuit. Fig. 2 shows the peak to peak video as normal, and with the addition of data and dispersal. We can see that, not only is the peak to peak level handling requirement much higher, but the item most likely to run out of headroom is the data train.

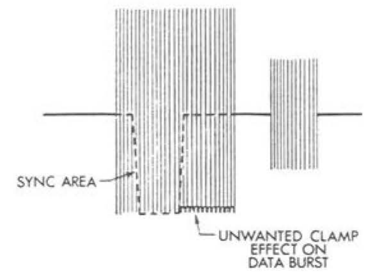


FIG.1

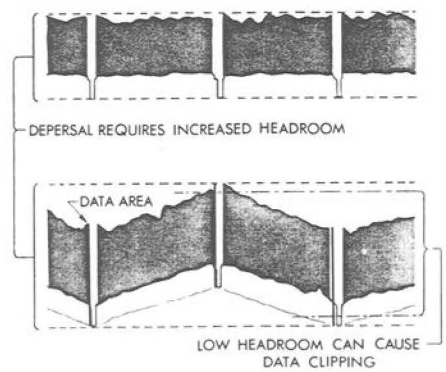


FIG.2

Solutions

One of the more successful approaches to these problems lies in the application of FM compression/ EDW feedback. The application of this technique allowed both major problems to be addressed simultaneously (Fig. 3). A typical FM compression receiver operates in the following manner. After demodulation, a sample of the energy dispersal waveform is extracted, and fed back to the front end. It then drives a tuning element which corrects the input tuning in time and out of phase with tne dispersal. The result is that the entire dispersal deviation is removed before IF filtering and video demodulation.

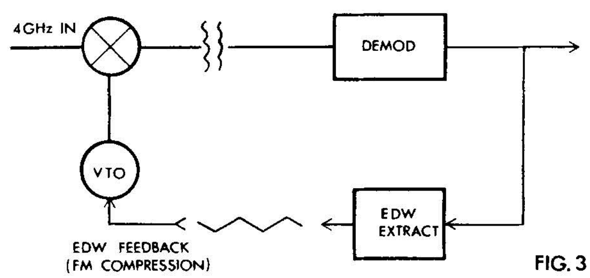


FIG. 3

The immediate effects are a) the peak to peak deviation and the peak to peak video level are reduced before processing; b) the removal of the dispersal eliminates the need for any kind of clamping circuit, and therefore any clamping distortion. Because the dispersal rejection is active, no correction is required for different dispersal levels. A receiver of this type is highly transparent to any form of data/video combined signal. A side benefit is that the FM compression, by reducing truncation noise in the IF filter, provides an immediate, dramatic improvement in dynamic threshold. FM compression receivers can operate with encrypted signals well below the encryption manufacturers' minimum G/T and C/N requirements and allow satisfactory performance with many of the 10' remote systems.

As we are aware, Data and RF are two very different sciences. Video is in itself a specialized science, and not one which is fully understood by most Data or RF technicians.

In most cases the RF people are unaware of the video baseband of their system, and the data people assume that the video will be well maintained.

The encryption system may be designed to regenerate sync at the decoder, and if so, it will be perfect in both level and form. If the video provided to the encryption unit or to the decoder, varies in level or content from ideal, difficult situations arise. It may sound like a simple matter to control, but, how do you measure video level with sync removed, data added, and video content altered for security? Problems in this area have and do arise, and usually result in much finger pointing and yelling. Point of note: a cable operation receiving encrypted video had better have someone available with the equipment and expertise to handle baseband video.

12 GHz PAY TV

The transition to KU band for pay television, which began with ANIK C, has been brought about by several factors. Because the 11.7-12.2GHz band is dedicated to television downlink, there is no prolem with terrestrial interference. Because there are no terrestrial links to be interfered with, higher downlink powers are possible.

The shorter wavelength allows smaller receive antennas as well as more control of beam shaping. ANIK C operates 16 transponders, each capable of carrying two channel simultaneously one half transponder format. These transponders are arranged to transmit 8 transponders (16 channels) to the western half of the country on vertical polarization, and 8 transponders east on horizontal (Fig. 4). The online date for this service and format, was preceded by about two weeks of occasional test patterns, making for a terrific scramble on "PAY" day. There were three reception methods available, in limited supply, to the cable operators, and many systems are not yet activated. The available hardware consists of:

A) some experimental 12GHz LNC receivers (single channel per down converter)

B) new block downconversion receivers (LNB) which require all new equipment to be purchased.

C) 12GHz to 3.7-4.2MHz block converters which allow the reuse of existing 4GHz receivers.

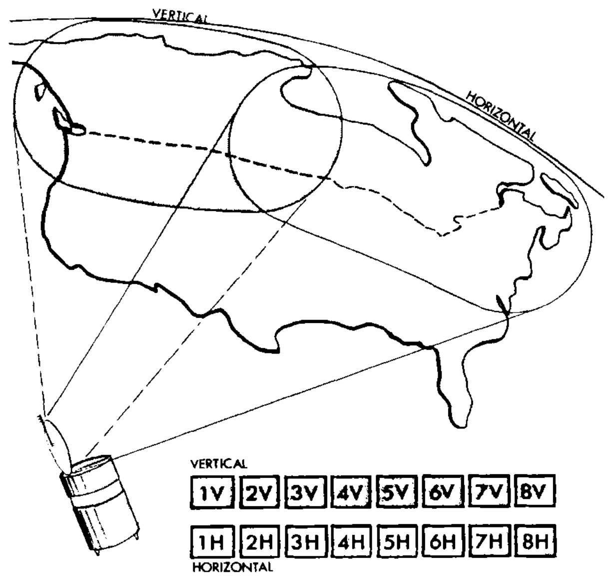


FIG.4

The supply and cost of this equipment presented the major problem, particularly when many operators were acquiring a 12GHz TVRO as their first TVRO. Each type of receive system had its peculiarities and required adjustments both in equipment, and in the way we think about TVRO systems.

The first item of concern was the antenna. Surface tolerance at 12GHz is quite critical, and many existing 3.5-4.5M C band antennas do not perform as well at KU band as a properly designed 1.5M 12GHz antenna. In order to provide margin and high G/T, most cable operators opted to purchase new 12 GHz antennas in the 3.5-4M size, but some tried to use whatever they had available. From the antenna, there are three systems available to recover the 12GHz signal (Fig. 5). The LNC system could be used by operators wanting only one Pay Channel. The LNC consists of a 12GHz low noise stage, followed by an image reject mixer, and a tunable local oscillator. The oscillator is remotely tuned from the receiver, and converts the desired channel to a low IF (i.e. 70 or 140MHz) which is transported to the receiver on low cost coaxial cable.

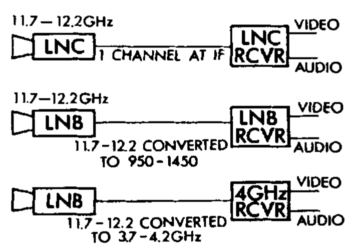


FIG.5

LNBs to high IF or to 4GHz were available, and both are widely used. The LNB to 4GHz converts the 11.7-12.2 band to 3.7-4.2GHz. A standard 4GHz receiver is realigned for the narrow IF requirements of half transponder transmission. The audio circuits must be realigned to the telesat frequencies (5.41, 6.17MHz) and the channel tuner must be realigned to accommodate the ANIK C frequency plan. The signal is carried to the receiver on microwave cable and can be split with regular 4GHz dividers to feed as many as required. This system is still rather expensive, because the block converter is a telecom/military product, and is not yet mass produced for cable.

The most successful method appears to be the LNB receiver designed for cable television. The primary features are a low noise front end (3-4dB), followed by a mixer, and driven with a dielectrically stabilized oscillator (DSO). The 11.7-12.2GHz band is block converted to an IF of approximately 1GHz. Design frequencies vary, with 270-770 and 950-1450 being the most common. There is pressure from the FCC to standardize on 950-1450, but many manufacturers are stocked with components for other bands. The signal can be transported on regular 75 ohm CATV cable and fed to as many receivers as required. The receiver can be essentially any LNB compatible receiver which operates in the proper input band; however some retuning may be necessary. The channel allocations for 12GHz and 4GHz, when converted to 950-1450 do not fall on the same frequencies. Receivers must be rechannelized depending on the block converter employed. Block converters of this type, for 12GHz are also in short supply, with very few manufacturers involved in the market. The price remains high, and delivery, slow.

Anik C Broadcast Format

The delivery via KU band on Anik C presented to the operator a new channel format as well as a new frequency band. The downlink band consists of two banks of eight transponders (eight vertical and eight horizontal). Each transponder is 54MHz wide with a 7MHz guard band, and each contains two similarly polarized channels at ±13MHz from center frequency (Fig. 6). The receivers employed on this service must meet two new operating requirements. The receiver must be able to select one 27MHz portion of the transponder while rejecting the adjacent. Remember that Satcom III's channels are 20MHz spaced and cross polarized alike. The receiver must also be able to tune transponders which are not incremented: that is, the space between channels is not equal and consistant.

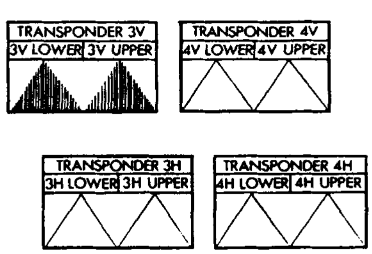


FIG.6

The problems are not too severe with receivers sold as part of a KU system, but do occur when conversion of existing C band equipment to KU is performed.

DIRECT BROADCAST SATELLITE

The licensing of STC to carry DBS in the near future has been met with negative views by the cable industry. In fact, DBS can not, and will not adversely affect cable. The delivery of a relatively small number of channels via antenna can easily be outdone by cable in any built-up area. The low delivery cost of cable combined with the high channel capacity, and, not to be forgotten, the low capital outlay from the customer, is an unbeatable combination. DBS will, contrary to popular belief, open a whole new dimension in the cable/satellite connection. The requirement for high volume KU band receivers will provide the thrust needed for developments in a relatively new science: GaAs MMIC.

Gallium Arsenide Monolithic Microwave Integrated Circuits (GaAs MMIC)

Today, LNAs, DSOs and other microwave circuits, are manufactured with a technique known as Hybrid MIC (Fig. 7). In a hybrid, part of the circuit such as couplers, resistors and stripline conductors are deposited on a dielectric substrate. Transistor and diode dies, as well as other components, are bonded to the conductors and connected with fine wire jumpers.

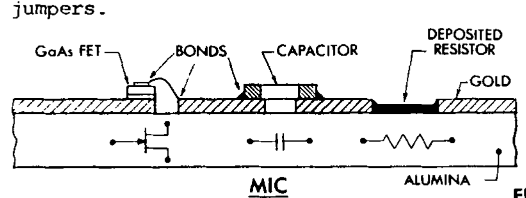


FIG. 7

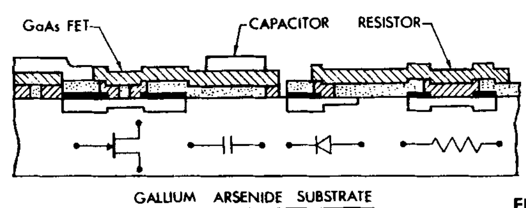


FIG. 8

This circuit involves a high degree of hand micro assembly, and the result is high cost.

The GaAs MMIC is a multi-layer construction which begins with a Gallium Arsenide substrate. In the manufacturing process, the transistors (FETs) and diodes are built up along with the other circuit components. We are able to build an integrated circuit (Fig. 8) almost totally by machine, with very few hand connections or extra components.

The DBS receiver could consist of (Fig. 9) two integrated circuits: one GaAs MMIC incorporating KU low noise input to IF output, and one conventional monolithic circuit incorporating an IF amplifier, demodulator and baseband processor.

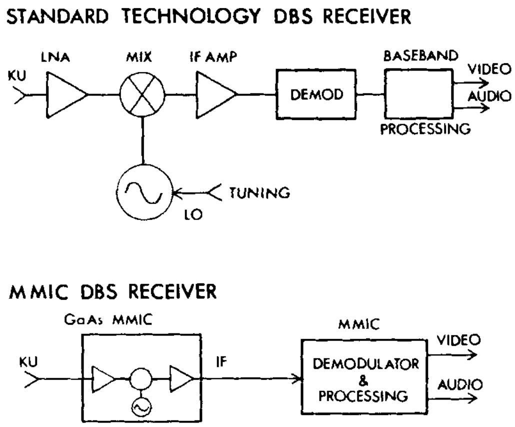


FIG.9

Influence of DBS Technoloy on Cable

Once implemented, this technology could reduce the average receiver cost to well below $200.00 including low noise amplifier. While this technology is initially being applied to high KU (12.2-12.7GHz) for DBS, it will probably spin off into the cable KU band (11.7-12.7GHz). One major potential could be realized when the KU band traffic becomes established for cable services. GaAs MMIC receivers could make it possible to build a system of multi head ends, at lower cost than a supertrunk or AML Hub system. We can forsee, in the future, that a 20 channel satellite receiver head end could cost less than 2 miles of trunk. Many small population pockets could now be served with individual mini-satellite hubs, occupying not much more space than a conventional AML receiver. This will not happen overnight! We will be employing conventional receive equipment for many years to come, but the potential for change is there. We must remember, the DBS traffic will probably consist of lighter loading than cable traffic. The services received by the cable operator, even today, include many non television components. The inclusion of multiple subcarriers, teletext and other services leave a wide performance margin between DBS and CATV quality receive equipment. Indeed, the major problem will probably not be the GaAs MMIC, but the receive process MMIC design.

CONCLUSION

The events of the last year will have significant effects on the cable/satellite connection. Within the next six months, we will probably all be having our first experience with satellite encryption. KU band input sources are not far behind. In general, the changes that will affect the cable operator are itemized as follows:

Today

-Encryption will require an improvement in system G/T as well as general receive equipment quality.

-Encryption will require improved video performance, and in many cases, will require that the operator have more comprehensive understanding of video, as well as more video test equipment.

Tomorrow

-Conversion to 12GHz band will require more accurate antennas and extensive modification to existing equipment.

The Future

-DBS will probably reduce the actual equipment cost, and result in new system design possibilities for the operator.

The future of the Pay TV Satellite/Cable system may have a few rough moments, and will require that some operators learn some very big lessons in a very short time. The end result, whether C or KU band, will be higher performance systems and higher performance equipment. We will not, in the age of KU encrypted signals, get away with previous bad habits and corner cuts. We must grow with the system.

THE DESCRAMBLER INTERFACE, A PROGRESS REPORT

Elliott S. Kohn

RCA Laboratories
Princeton, New Jersey 08540

ABSTRACT

The incompatibility between full-feature TV receivers and cable systems with scrambling has been discussed before in this forum, and is well known in the industry. TV receivers that tune the special cable channels are available, but their sophisticated tuning and remote-control features cannot be used in scrambled cable systems providing combined converter-descramblers. Last year, we proposed a standardized decoder interface for TV receivers, that would permit cable operators to supply relatively inexpensive decoder modules to subscribers for use with such receivers. The Electronic Industries Association and the National Cable Television Association have sponsored working groups to define such an interface. Considerations included which types of scrambling can be provided for without compromising cable security or unduly burdening the manufacturing cost of TV receivers. Connections useful for other video accessories as well as descramblers are obviously preferred. The problem is complicated by the numerous scrambling methods in use and being introduced. The progress of the industry working groups will be discussed.

Introduction

The problems of cable-ready TV receivers in scrambled cable systems are well known in the industry. I originally discussed the problem at the Western Cable Show in Anaheim, CA in December 1981, and again at ICCE in June 1982.[1] There, I showed that cable-ready receivers operate well in cable systems secured by the trapping or jamming of pay channels, but have a serious problem in cable systems secured by scrambling. The problem is illustrated in Fig. 1, which shows a typical converter-decoder supplied by the cable operator, used with a TV receiver. While the TV receiver may have remote control, and may have a very sophisticated tuner covering all the required cable channels, these features are wasted when the receiver is in a cable system requiring the converter-decoder to be used ahead of the receiver in order to descramble the premium channels. The duplication of the tuners and remote control equipment adds to the customer's cost, and can only be detrimental to the performance and to the operating convenience of the system. In the earlier work, I proposed the descrambler module that would plug into a standardized descrambler interface connector on the TV receiver. The module would be supplied by the cable operator, and would provide for the descrambling of those programs that the customer has ordered, just as the converter-decoder does now. The module would provide for recognition of program tags, and could be addressable if desired. I proposed the signals shown in Table 1 for use at the interface. This list was by no means intended to be the finished product. Rather, it was a starting point, including all signals thought to be available in TV receivers, that could be useful for interfacing minimum-cost descrambler modules for the various known scrambling systems. It was clear that a recommended standard along these lines would require a concensus among TV manufacturers, cable product manufacturers, and cable-system operators.

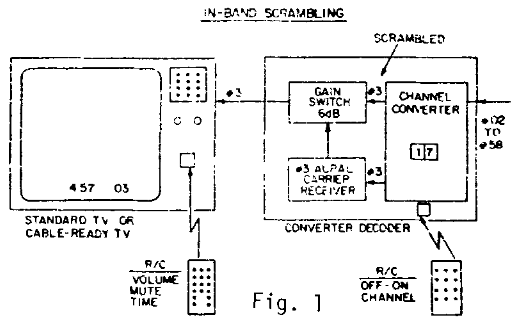


Fig. 1

Industry Activities

1982 has indeed been a year of intense industry activity in solving the compatibility problem. Early in the year, the EIA and the NCTA formed the Joint Commmittee on The Cable Interface, headed by Robert Rast. A working group on cable channel identification, also headed by Rast, succeeded in preparing a cable channel identification plan that will clear up much of the confusion that presently exists in cable-channel numbering. With that work complete, two new working groups have been established, one on The Cable Interface, headed by Walter Ciciora, and the other on Interface Alternatives, which I chair. The EIA receiver committee also has an active working group on The Decoder Interface, headed by James Hettiger. All of these groups are administered by Tom Mock of the EIA. While the job is by no means completed, a great deal of progress has already been made. The cooperation among the three industries involved has been very encouraging.

Table 1

Possible connections at decoder inteface

1. Loopthrough of cable from tuner to IF amplifier.

2. Loopthrough of detected video signal with level and polarity specified.

3. Loopthrough of audio with level specified.

4. 4.5 MHz audio IF signal for data receiver.

5. Wide-band audio ahead of de-emphasis for off-air systems with multiplexed audio.

6. Loopthrough of cable from antenna terminal for out-of-band telemetry channel.

7. Power for decoder module.

General Considerations

Before deciding what signals to include at the interface, it is necessary to settle on which scrambling methods can and should be provided for. The most widely used scrambling methods presently are sync suppression of the pulsed and sine-wave types. However, it is the mood of the cable industry that these systems do not provide adequate security, and that within a few years, more sophisticated scrambling methods will be widely used. This is the same time frame required for a decoder interface, if approved this year, to become widely available. Thus, we have the following reasons for not providing for sync-suppression descrambling at the interface. 1) An interface providing for sync-suppression descrambling would make it too easy for the customer to use home-built or commercial pirate equipment to defeat the system. 2) It is not clear that cable operators will ever buy sync-suppression decoder modules, because in the time frame when the decoder interface becomes available, converters-decoder boxes for sync suppression are likely to be available as surplus, since many systems are expected to convert to more secure methods. There is also the matter 3) of whether the pilot signal required for pulsed sync-suppression descrambling, is really available in TV receivers without costly modification. The pulse amplitude modulation of the aural carrier in such systems has a bandwidth of over 1 MHz, and would be best handled in a TV receiver with a special AM receiver at 41.25 MHz, the sound IF.

Baseband Descrambling

The baseband video loopout is clearly the most important signal in the interface, and the most attention has been given to the problems in standardizing it. This loopout will provide for black-to-white inversion systems, time permutation systems, and any other baseband scrambling methods developed. It also makes available timing, tag and address information sent in the video signal during the vertical blanking interval. The vast majority of the committee members believe that this loopout should have standard 1-volt video, terminated in 75 ohms, thus maintaining compatibility with other video accessories. A video loopout with non-standard signal level and impedance has also been proposed in an effort to get decoder modules into the field more quickly and at lower manufacturing cost. This method, however, offers these advantages only with TV sets of a particular design. Most participants do not consider it a suitable standard.

A subtle, yet critical issue with the video loopout is the handling of the TV's automatic gain control (AGC). TV receivers, whether or not they employ AGC keying, usually rely upon peak of sync to establish the correct gain in the IF stages and in the tuner. A TV receiver whose AGC system is designed to give the correct amount of tuner and IF gain with standard video, will not operate correctly on sync-suppressed video. The video signal will be amplified too much, and the amount of gain will vary with scene content. To get correct operation with the sync-suppressed signal, it is necessary to do the sensing for AGC after the sync is corrected, hence, after the video loopout if a module is to be used. The AGC sensing could be done within the TV receiver using the signal returned to the TV receiver by the decoder module, as shown in Fig. 2. Buffering and isolation, not shown in the figure, may be needed. An AGC control voltage determined by the returned video signal can be looped back to the IF stages and to the tuner completely within the TV receiver. No separate AGC control voltage needs to be involved at the decoder interface. The decoder module is necessarily in the forward path of the TV receiver's AGC loop, but it has no major effect on the TV receiver's AGC loop characteristics, and the module manufacturer is not taking control of the receiver's AGC loop in the sense for which concern has been expressed by TV manufacturers. The decoder module is necessarily DC coupled, and it will probably require a trim pot for DC offset. A TV receiver built with this interface differs from current TV receivers only in that the standard terminated video loopout is provided, and that the DC sensing is done after the return of the loopout, instead of within the IF chips, as is current practice. This method has the advantage that the decoder module is minimally involved in the receivers AGC loop. A different proposed method would have the AGC sensing done in the decoder module, and a control signal returned to the TV's AGC system through a dedicated interface pin. The AGC issue has not yet been resolved.

The IF Loopout

The IF loopout was originally proposed for RF descrambling, where the pilot information is amplitude modulated on the aural carrier. More recently, it has been proposed for use with a baseband decoder module having its own IF stages

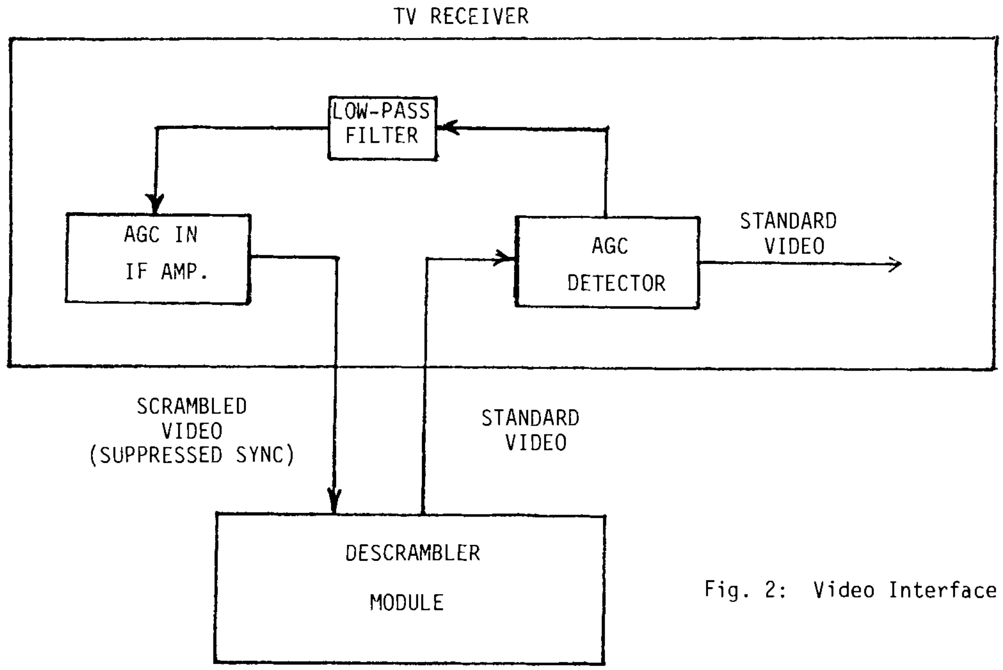


Fig. 2: Video Interface

and video and audio demodulators. This decoder would return baseband video and audio to the TV receiver, using the receiver only for its tuner and monitor functions. An IF loopout of this type has the problem of supplying correct AGC and AFT control signals to the tuner, since the internal IF amplifier will not be operating correctly. The IF loopout does not presently have a consensus going for it.

The Audio Loopout

Although there is presently very little scrambling of audio for pay-TV, cable operators are in agreement that audio scrambling will be an important part of their security in the years to come. There is a consensus that the decoder module should provide for audio descrambling.

Three types of audio connections have been considered: 1) baseband audio in and out, 2) wideband composite audio in and out, and 3) 4.5 MHz audio. The 4.5 MHz output from the TV receiver was intended for sync-suppression descrambler modules, and has been dropped from consideration. Wideband audio, taken ahead of deemphasis, is desirable as an output from the TV because it makes possible descrambling by the module, of audio, scrambled or encrypted through the use of subcarriers on the audio carrier. Good-quality wide-band audio will be readily available in a few years from TV receivers having multi-channel sound. Wide-band audio, ahead of de-emphasis, is not available in many current receivers. Even if it were made available, the intercarrier conversion, as it is done in current receivers, might impair the quality that signal. Wide-band audio, as an input to tne TV receiver, from the module, is probably not needed, as descrambler modules will probably not return composite stereo to the TV receiver when they can simply return right and left audio channels. Baseband audio inputs to the TV set are needed to return this decoded audio as baseband right and left channels. Right and left audio outputs from the TV set are useful because they permit modules, intended for video-only descrambling, to loop the audio back to the right and left inputs, with no additional switching complications. The decoder interface will probably be a multipin connector with automatic jumper switches for the video and audio loopouts.

Cable Loopthrough

Many addressable cable-systems have their address data on a separate carrier, outside of the TV channels. While the TV receiver cannot be expected to demodulate this data channel, the descrambler module can, if it is provided with a loopthrough of the cable. This cable loopthrough would be in addition to the multi-pin interface connector, where desired,and is shown in Fig. 3.

Power

The interface could be defined to include limited power supplied by the TV receiver to the descrambler module. Modules requiring higher power, or needing their out-of-band address receivers maintained continuously, can, of course, be provided with a separate power cord. Descrambler modules, however, lacking the tuners and IF circuits of baseband converters, will consume far less power than our current converter-descramblers. Inclusion of a power pin in the interface would encourage the development of low-power modules within a few years. A concensus does not presently exist for this feature.

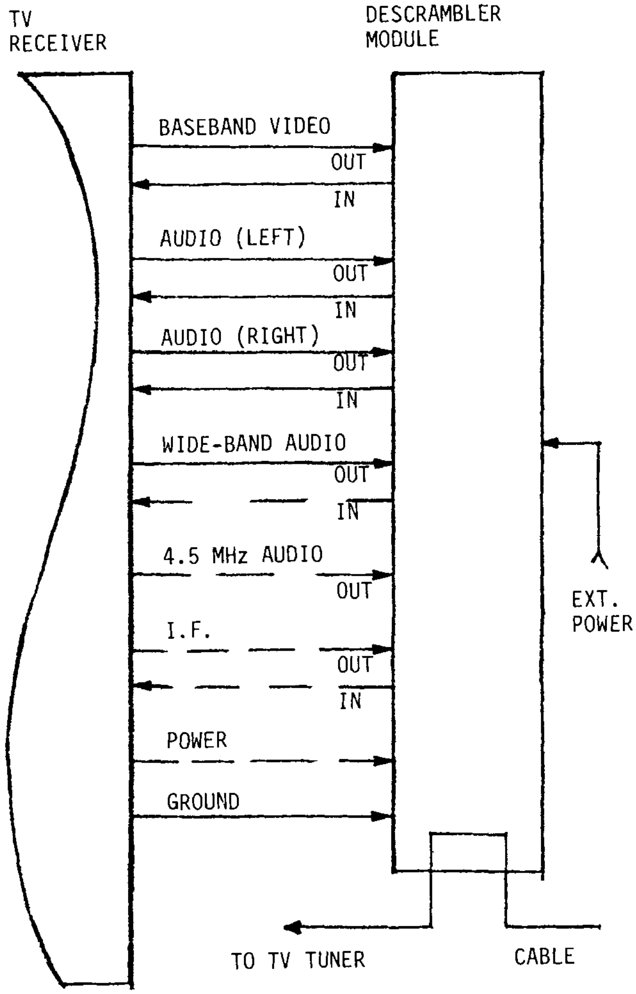


Figure 3: The descrambler module, showing the descrambler interface and other connections.

Conclusion

The problem of compatibility between full-feature TV receivers and cable systems has received considerable attention in the past year. Cable operators have announced a willingness to use the interface when it becomes available. Unsettled questions, of course, remain. Among them is the important question of isolation and safety. While work remains to be done, the progress to date has been very encouraging, and we have reasonable hope of seeing truly cable-compatible TV receivers within a few years.

References

1) E. S. Kohn, "Scrambling and Cable-Ready TV Receivers", IEEE Trans. on Consumer Electronics, CE-28, #3, 220-225, August 1982.

THE DESIGN APPROACH TO A NEW CATV DISTRIBUTION AMPLIFIER

Alan J. Schlenz

SCIENTIFIC-ATLANTA, INC.

ABSTRACT

Greater demands on the performance of cable television systems have imposed stringent requirements on distribution equipment. This paper discusses some of the problems encountered and solutions to meet these requirements in a low cost, high performance amplifier. Specific topics include discussion of packaging, implementation of optional accessories, return loss and response optimization, and control of loop isolation.

INTRODUCTION

Trunk to feeder ratios have been continuously increasing, because of extended bandwidths and increased subscriber density, making it desireable to cascade more line extenders in order to reduce the system cost. Distribution line extenders have generally been high gain devices with simple manual gain and slope control. The lack of high performance automatic gain and slope amplifiers having two way capability has limited the number of units that can be cascaded due to the attenuation of cable and passives changing with temperature. Set top converter and television receiver performance determine the maximum allowable signal variations on the feeder system. With tighter feeder response control, more feeder amplifiers can be cascaded and the number of trunk stations reduced, resulting in lower system cost.

To provide increased system control and flexibility a distribution amplifier was designed to meet the following goals:

- Improved frequency response
- Flexible configuration/modular construction
- High forward and return gain capability
- Optional AGC
- Optional switching regulated power supply
- Standard and extended bandwidth capability
- Multiple split frequencies
- Increased reliability
- Cost effective

These design goals pose numerous technical and mechanical problems, some of which are discussed in the following sections.

TECHNICAL CONSIDERATIONS

High forward and return gain capability with extended bandwidth complicates the implementation of improved frequency response. Present day hybrid amplifiers have extremely good frequency response and return loss specifications. However, when the hybrid is interfaced with a printed wiring board (PWB) mounted in a module, both specifications are affected by ground currents. Most broadband CATV line extenders utilize coplanar transmission lines. Discontinuities cause some of the signal to be propagated across the ground plane where it combines at sensitive portions of the circuit and distorts the frequency response.

Discontinuities occur primarily where circuits such as diplex filters built on the main RF circuit board disrupt ground plane and at the interface of the hybrid amplifier. The pin arrangement for commonly used hybrids has ground connections only on one side of the RF input/output pins. A coplanar transmission line requires a large continuous ground surface on each side of the center conductor. If some method is not provided to contact both sides of the hybrid ground, stray currents around the hybrid will be set up causing a poor frequency response. Oscillations can occur when the module is being inserted into the housing if proper grounding is not maintained at all times. The problem is compounded when using higher gain hybrids or hybrids in cascade. Connecting the ground to the hybrid by a small clip contacting the hybrid heat sink substantially reduces the problem.

A reduction of stray ground currents is realized by constructing the diplex filter and trim networks as plug-in units and using an interface which is an extension of the transmission line. The coaxial connector shown in Figure 1A and the pin arrangement in Figure 1B provide excellent interfaces. Plug-in accessories are helpful in controlling stray current paths because they maintain large ground areas on the main RF board. When circuits are constructed directly on the RF board the ground area is broken up, increasing stray ground paths.

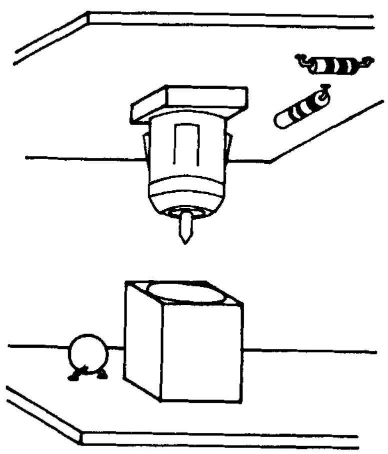


Figure 1A

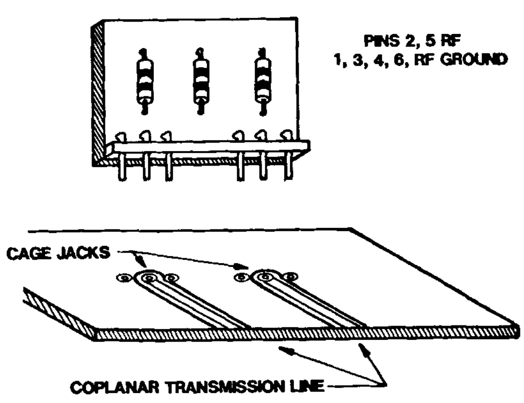


Figure 1B

The ground current problem is more critical in bi-directional amplifiers. When a single PWB is used a common ground exists between the forward and reverse circuits. This causes poor isolation between amplifiers resulting in distortion in both forward and reverse frequency responses. The magnitude of the distortion is again a function of hybrid gain and isolation. By providing a septum as shown in Figure 2 and separating the single PWB into two parts, the common ground is eliminated. The septum must be electrically grounded directly to the module input/output coaxial connectors to be most effective.

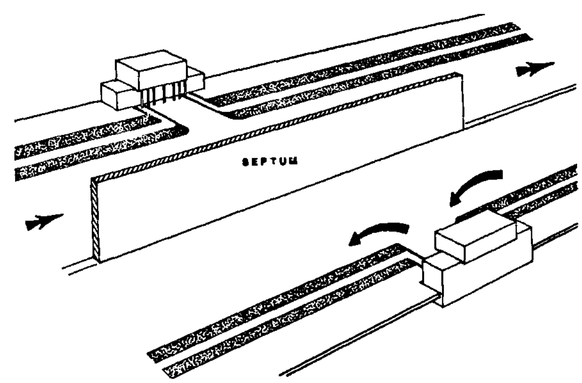


Figure 2

The RF module interface to the seizure system is also affected by stray ground currents. The module-to-housing interface must have a reliable continuous electrical ground and the seizure system should have minimal impact on input/output return loss. Cable powering and lightning induced surges necessitate an AC bypass coil and high pass filter. Separate PWB's with coaxial connectors were used to closely approximate a continuous transmission system. This arrangement produced greater than 30dB return loss for the seizure and also provided for a simple powering arrangement. Removal of the RF module does not interrupt the system AC power. Care must be exercised in the design of the AC bypass coil to prevent self resonances or resonance with parasitic capacity to ground.

Even with these precautions, stray currents will exist at low levels causing small variations in the amplifier response when metal covers are removed and replaced. This can be annoying during balance and alignment. By utilizing a noncunductive cover the effect is eliminated.

Having minimized the stray currents, attention can be focused on the direct path loop isolation. Two desired paths exist through the forward and return amplifiers as shown in Figure 3. These paths are established by the diplex filters which consist of high and low pass filters with high isolation (better than -40dB) between the low and high ports and minimum attenuation (less than .5dB) for the desired paths. An undesired loop exists which is shown in Figure 4. The gain around this loop is the sum of all gains and losses defined by equation (1).

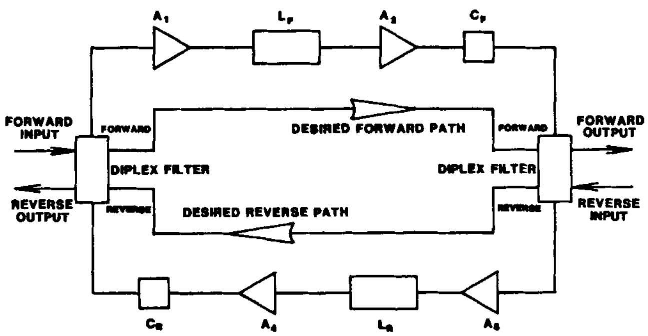


Figure 3

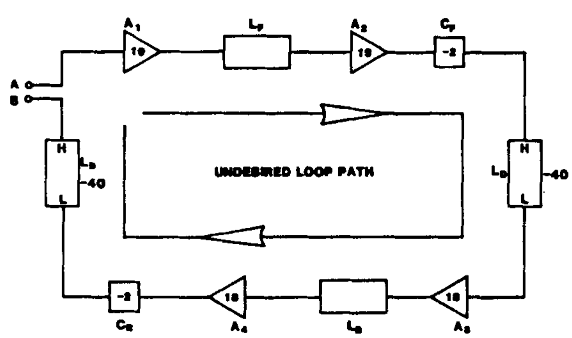


Figure 4

$$GL = A1 + LF + A2 + CF + LD + A3 + LR + A4 + CR + LD \quad (1)$$

GL = Loop Gain

A1-4 = Respective hybrid gains

LD = Diplex filter isolation losses

LF, LR = Forward and reverse filter losses

CF, CR = Forward and reverse PWB losses

If this number is greater than unity oscillation may occur. Loop gains less than unity will not produce oscillations but the frequency response will exhibit ripple. Equation (2) is an expression for the peak-to-peak ripple that can be expected for a given loop gain.

$$Rpp = 20 \log \frac{(1 + 10^{GL/20})}{(1 - 10^{GL/20})}, \quad (2)$$

where Rpp is the peak-to-peak ripple in dB, and GL is the loop gain determined by (1).

Using equation (2) for a GL of -45dB yields the following Rpp:

$$Rpp = 20 \log \frac{(1 + 10^{-45/20})}{(1 - 10^{-45/20})} \quad (3)$$

$$= .098 \simeq .1\text{dB}.$$

For -45dB loop gain a maximum of .1dB peak-to-peak ripple can be expected. Using the realistic numbers shown in Figure 4 the loop gain is:

$$GL = 19 + 19 - 2 - 40 + 18 + 18 - 2 - 40 = -10\text{dB}. \quad (4)$$

(LF and LR assumed equal to 0)
This would produce a peak-to-peak ripple of 5.7dB, and therefore additional filtering is required. Plug-in interstage filters were designed which have more than 40dB attenuation in the reject band. Two filters are required, one high pass and one low pass. Notice that as the gain of the hybrids increases the filtering requirement increases. However, filter stop-band attenuation of 40dB is more than necessary for the maximum practical Distribution Amplifier gain.

Automatic gain and slope control requires greater hybrid gain to make up for losses in the gain and slope networks as they compensate for cable and system temperature dependent losses.

AGC CAPABILITY

Performance and new applications dictate AGC capability in the Distribution Amplifier. In order to implement this feature in a cost effective manner a modular package was developed. This allowed a voltage controlled RF circuit to be designed as a plug-in unit for the RF module PWB. This unit can be easily replaced by a jumper where automatic control is not required. A separate module located in the housing lid develops the control voltages for the RF circuit. A cable harness provides the required interconnections. This method makes maximum use of available space so the overall amplifier dimensions can be minimized.

RELIABILITY

The power supply and AC transformer were also located in the housing lid which allowed for more even distribution of the heat sources resulting in cooler heat sink temperatures. This directly affects hybrid reliability. The graph of Figure 5 [REF 1] is a plot of hybrid failure rate multiplier verses heat sink temperature. The graph indicates the reliability of a hybrid operating at 90°C verses 110°C heat sink temperature is 30% better, and would significantly reduce system down time due to hybrid failures.

The switching regulated power supply reduces system power consumption and increases reliability by dissipating less heat than a linear regulated supply. To provide a low thermal resistance path for the hybrids and power supply heat sinks to the ambient air the hybrid mounting technique of Figure 6 was used. This provides a short thermal path to the housing through two large surface areas reducing operating temperatures. The result is a maximum thermal rise of less than 15° C between the hybrid heat sink and housing. Cooling fins cast into the housing bottom and top increase the housing surface area which transfers the heat into the ambient air. The pass transistors in both switching and linear power supplies are connected directly to heat sinks cast into the power supply frames. The heat sinks in turn fit flush against the inside of the housing lid. The 60 Hz AC transformer is mounted directly to housing bosses that provide heat sinking and allow for an optional 50 Hz transformer (Figure 7A and B).

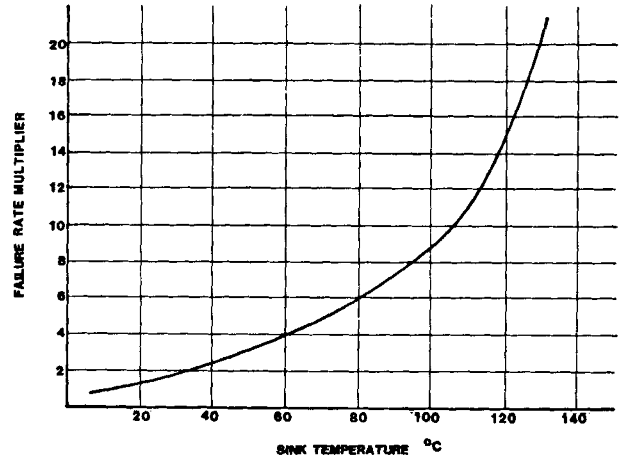


Figure 5

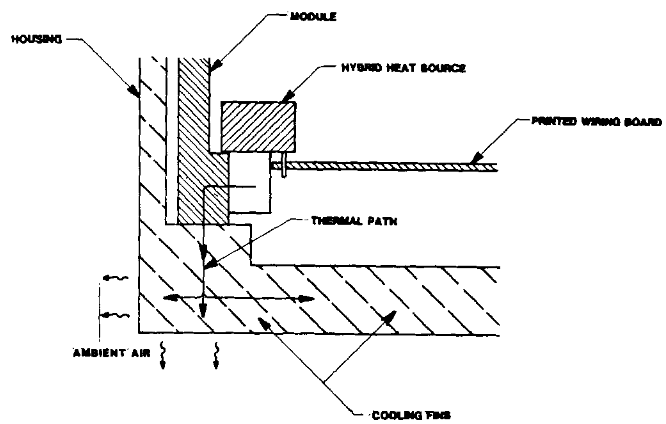


Figure 6

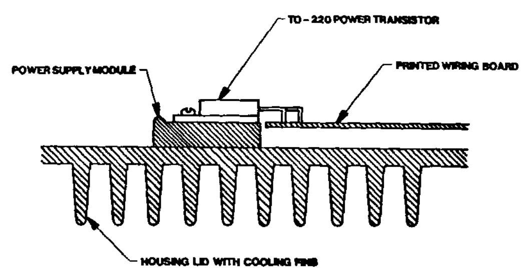


Figure 7A

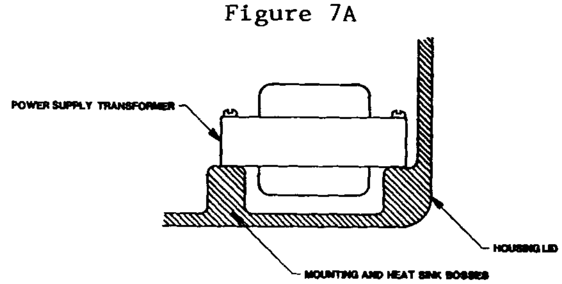


Figure 7B

MODULARITY

The flexibility of this modular configuration has produced an amplifier having two-way high gain capability, optional AGC and optional switching regulated power supply. In addition, the plug-in accessory (diplex filter, interstage filter, trim network, AGC RF) concept used in the RF module accomodates a variety of forward and reverse frequency splits. The appropriate networks need only to replace the jumpers in the basic RF module to produce the desired frequency configuration. Because each of these networks is a stand alone 75 Ohm input/output device, they can be aligned and tested independently to assure each part meets the required performance specifications.

Cost effectiveness is achieved because the individual modules can be optimized for efficiency in manufacturing and testing. This produces high quality modules with optimal performance specifications. System inventory is reduced because the same basic module is used throughout with total interchangeability of parts.

With this modular approach the system can be upgraded at any time. Extended bandwidth becomes a function of hybrid response as all other components have been predesigned to accomodate higher frequencies.

An important benefit of the modular design used is that specialized circuits and new technology can be easily implemented allowing the manufacturer to more effectively meet the needs of the continuously changing CATV industry.

REFERENCE

1. Vaughn, Wayne, Design Considerations For Mechanical Packaging of a CATV Trunk Amplifier, 30th Annual NCTA Convention Technical Papers, 1981, pps. 134 - 142.

BIBLIOGRAPHY

1. Gupta, K.C., Ramesh Garg and Rakesh Chadha, Computeraided Design of Microwave Cirucits, Massachusetts: Artech House, Inc., 1981.

2. Hayt, Wi8lliam H., Jr., Engineering Electro-Magnetics, 3rd Edition, New York: McGraw-Hill Book Company, 1974.

3. Jordan, Edward C. and Keith G. Balmain, Electro-Magnetic Waves and Radiating Systems, 2nd Edition, New Jersey: Prentice-Hall, Inc., 1968.

THE IMPACT OF MULTICHANNEL SOUND ON CATV SYSTEMS

Joseph Van Loan

Viacom Cable

Pleasanton, California

A proposed Multichannel Sound (MCS) System for television is described, and differences between three proponent systems are discussed. Each of the proponent systems includes provision for transmission of:
1. L+R information to maintain compatibility with existing receivers
2. L-R information for stereo
3. A Second Audio Program (SAP) channel for a second language, quadraphonic sound or as a tutorial channel; and
4. A non-public channel for voice and/or data telemetry.

Although immediate wide-scale implementation is not expected, the planned system may have a substantial financial impact on the CATV industry. Headend equipment (including processors, modulators, demodulators and microwave transmitters and receivers) may have to be modified or replaced before passing an MCS signal. Present day descramblers will likely suffer deteriorated performance when used on MCS signals, and the MCS signals themselves may suffer degradation when used with descrambling equipment. The introduction of MCS carriers with their increased bandwidth and possible higher levels on a CATV system raise questions about the ability of present day receivers to trap out sound carriers on lower adjacent channels.

The MCS Subcommittee of the NCTA Engineering Committee is conducting tests in cooperation with the Electronics Industries Association and the National Association of Broadcasters to determine the impact MCS signals will have on the CATV industry and to recommend which of the three proponent systems, if any, should be selected.

INTRODUCTION

Multi-Channel Sound for Television and its Implications for CATV

In 1979 the Consumer Electronics Group of the Electronics Industries Association, the National Association of Broadcasters and the Joint Council of Inter-Society Coordination formed the Multichannel Sound Subcommittee to study proposals to introduce multichannel sound (stereo) into the U.S. television system. In August, 1982 the Committee published a 1,000 page report which contained results of tests conducted on three proponent systems.[1] EIA-J, Telesonics and Zenith have each proposed systems which are similar in many respects and different in others.

Each system will maintain compatibility with the existing monophonic system by transmitting an L+R channel with the same characteristics as the present monophonic channel. Each system will transmit stereophonic information using an L-R channel and a corresponding pilot in the spectrum above the L+R channel. A channel called a Second Audio Program (SAP) channel will permit the simultaneous transmission of additional aural information such as a second language or a narrative. The performance of this channel is limited both in fidelity and noise performance when compared with the stereo channel. Finally, a channel called the non-public channel is proposed to transmit data and voice information.

Figure 1 depicts the baseband spectra of each of the proposed systems. Each of the systems has undergone changes to improve performance as test results are analyzed. Most noteworthy among the differences are: the EIA-J systems uses an FM subcarrier for L-R transmission while the Telesonics and Zenith systems use double sideband suppressed carrier amplitude modulation (DSB-SC AM) for L-R transmission. Note, current practice for FM broadcast stereo in the U.S.A. uses DSB-SC AM for stereo transmissions. In the EIA-J and Zenith systems the L-R subcarrier is centered at twice the horizontal scanning frequency ($2f_H$), but in the Telesonics system, the L-R subcarrier is positioned at 2.5 the horizontal frequency. The SAP channel has been subjected to numerous changes. Figure 1 indicates the proposed configurations at the time of this writing.

In August, 1982 the NCTA Engineering Committee formed the MCS Subcommittee to study the impact that MCS will have on CATV system operation and

[1] "Multichannel Television Sound: The Basis for Selection of a Single Standard", by Electronics Industries Association's BTS Committee, Published by the National Association of Broadcasters, Vol. I, July 16, 1982; Vol. II, August 6, 1982.

to recommend one of the three systems if deemed appropriate. The Subcommittee set a precedent in early 1983 when professional help was retained to supplement the volunteer activity in studying the impact. The EIA/NAB Committee has made its laboratory facilities, located near Chicago, available to aid in the study. Tests are now being conducted in that facility with joint cooperation between the two groups.

TECHNICAL IMPLICATIONS FOR THE CATV INDUSTRY

A. Audio Signal/Noise Ratio[2]

In Volume I of the Multichannel Television Sound report, it was indicated[3] that for high quality sound reception, the signal to noise ratio should be at least 60dB, preferably 70dB or better, for the principal community of viewers. For comparison, EIA RS-250B specifies for monaural sound that the minimum unweighted audio SNR for end-to-end television relay facilities be 56dB, including buzz. We should deliver at least a 60dB SNR to the TV receivers connected at the extremities of our systems. To determine the expected SNR (thermal noise only) in cable systems, calculations were performed by several members of the NCTA Subcommittee.

For the case of 36 dB NCTA Video RF-SNR[4], with the sound carrier 15dB below the video peak envelope power, we get the following unweighted audio SNR's.

	Monophonic	Stereo L or R	SAP
Separate Mixing	63.8dB	49.2	39.6
Intercarrier, Video at Blanking Level	63.6	49.0	39.4
Intercarrier, Video at White Level	59.0	44.4	34.8

Obviously we are in trouble if there are subscribers whose ears demand stereo but whose eyes will tolerate 36dB. In addition, the Separate Audio Program SNR will be approximately 10dB less than stereo signal. If we assume that a more typical situation is for the cable system to deliver a 43dB Video SNR, then we find ourselves dealing with a stereo SNR or approximately 55dB and a SAP SNR of approximately 45dB. These are certainly more tolerable conditions and could be improved even more if companding is used. (A separate working group is developing a companding system).

From the calculations it appears that threshold margins are adequate, both for new sets with sound IF bandwidths sufficient to support the broadband signal and for old sets.

B. Visual/Sound Ratio

It is recognized that one way to improve the multichannel sound SNR is to increase the sound carrier level. Above threshold the audio SNR is increased one dB for each dB we raise the sound carrier level. In Volume I[5] of the EIA report, use of the highest feasible sound power is encouraged.

It must be recognized that increasing the sound carrier level in a cable system is undesirable and would create a multitude of problems, as explained in the following:

1. TV Receiver Adjacent Channel Rejection

All cable systems operate with TV channels adjacent to one another. In the early days of cable it was determined that most TV receivers lacked sufficient selectivity to provide for beat-free pictures, unless the lower adjacent sound carrier was reduced in level below the visual/sound ratio being transmitted by broadcast stations. Although the NCTA committee recognized that receiver selectivity has been considerably improved over the years, one must recognize that the proposed multichannel sound standards with their increased deviations (approximately 70kHz) creates sound carriers whose energy occupies a much wider bandwidth than before (approximately 320 kHz for 70 kHz deviation as compared to 80kHz for 25kHz deviation). In a paper written in 1972 by Will Hand of Sylvania entitled "Television Receiver Requirements for CATV Systems", tests were performed on a number of color receivers which represented collectively over 50% of receiver designs in the industry at that time. The data shown below is the weighted results of these measurements. The data was weighted to reflect the proportion of the market held by the receiver manufacturers.

[2] In order to simplify analysis and due to similarities between systems the Zenith was used for discussion and analysis except where clear differences are noted.

[3] Multichannel Television Sound: "The Basis for Selection of a Single Standard", Volume I, The National Association of Broadcasters, July 16, 1982, p. 51.

[4] Minimum allowed CNR for Cable Systems. Part 76 of FCC Regulations.

[5] Multichannel Television Sound Report, p. 164.

	Frequency (kHz)
Adjacent Sound null to 41dB point on low frequency side of IF trap	94
Adjacent Sound null to 41dB point on high frequency side of IF trap	115
The 41dB rejection bandwidth of this trap is 94 + 115 = 209kHz	

One can only conjecture what the rejection of this trap would be to a sound carrier adhering to the proposed multichannel sound standards; however, it goes without question that raising the sound level would only aggravate what already may be an unacceptable operating condition.

Set-top converters with adjacent channel traps would help, although only a few presently in the field have this feature. Separate traps connected to the output of converters and tuned to the lower adjacent sound would help; however, they suffer from the following problems:

a. AFC and fine tuning errors would diminish effectiveness.

b. They would introduce additional group delay errors.

c. The overall cost would be substantial.

d. Subscribers might confuse them with pay TV traps and remove them.

2. Headend Equipment (Signal Processors, Strip Amps and Modulators)

The majority of these devices operate at an output level between +50dBmV to +60dBmV (+60dBmV = 1 volt rms @ 75 ohms) for the video carrier with the sound carrier typically 15dB below this level. Most manufacturers also quote a specification which states that when the unit is operated at maximum output (this is not uncommon), all spurious outputs will be at least 60dB below the desired video carrier. One component of this distortion falls 1.5MHz above the video carrier of the lower adjacent channel. Any attempt to raise the sound carrier level causes a one dB rise in this undesired signal for each dB the sound level is increased. This is a particularly sensitive area of the video spectrum and any interfering carrier must be 55dB to 60dB below the desired carrier not to be perceptible. This problem is only aggravated when scrambling systems are employed which amplitude-modulate the sound carrier with descrambling timing information. The NCTA Subcommittee recognizes that this potential problem can be solved with highly selective bandpass filters on the output of these devices but not without an increase in the envelope delay distortion inherent in these filters. Equipment already in place may have to be replaced or undergo major modification to meet new performance standards.

3. AML Equipment

AML equipment is used to transmit channels of television from one area of a community to another. Increases in aural carrier levels would cause corresponding increases in the lower 4.5MHz products, as described in 2. above. For systems operating at full rated power, it would likely be necessary to reduce output power thereby reducing fade margin. The performance of this equipment is impaired by scrambling systems which cause a 6dB or more increase in the aural level during transmission of descrambling timing pulses. This practice creates a marginal condition to exist with today's practices. Increasing levels for Multichannel Television Sound would be unacceptable.

4. Distribution Equipment

Measurements were conducted to determine the perceptibility of sound carrier beats when the aural carrier levels were increased above 15dB below the visual carriers. From these measurements, perceptibility of sound-carrier beats occurs at a system level 3 to 3-1/2dB above that level which produces barely perceptible video carrier beats (CTB-composite triple beat distortion) when not phase locked. In the same test the system level could be elevated approximately 5dB when phase locked before background images (modulation cross-over) could be seen. These tests were performed with 54 channel Harmonically Related Carriers (HRC) loading. The conclusion to be drawn from these tests indicate if aural levels must be increased to accommodate Multichannel Sound, then the advantage gained from phase locking is lost.

Another problem may surface if aural levels are increased. Many cable operators find it possible to use certain channels in the aeronautical radio service bands by lowering aural carrier levels to +28.75dBmV maximum. In fact, several channels can sometimes only be used this way due to conflicts with both the visual and aural carriers. If aural levels are raised, this practice would be eliminated resulting in the loss of these channels for stereo service.

C. Increased Deviations

In order to achieve the highest possible stereo SNR, plus provide for auxiliary services, all proponents of the multichannel sound systems intend to increase the peak deviation to approximately 70kHz. By doing so, technical problems may be created in both cable headends and set-top converters, not to mention the selectivity problems of TV receivers. The following section discusses the nature of these problems in detail.

1. TV Receiver Selectivity (See Section B.1.)

2. Headend Equipment

a. Signal Processors

Two types are currently in use. One type uses a split sound system where the aural carrier is trapped and processed separately. The second type processes the video and sound combined and uses adjustable traps to reduce the sound carrier level. Both systems will suffer when deviations are increased from 25kHz to 70kHz.

For split sound units, the sound notch must not introduce amplitude or group delay errors in chroma information while attenuating the sound carrier and its sidebands at least 40dB. This has been achieved for 25kHz deviation with a Carson bandwidth of 80kHz. When the new Carson bandwidth for stereo (approximately 350kHz) is measured, attenuation of the upper sideband is on the order of 10dB. With incomplete trapping, a portion of the aural carrier passes through the visual processing circuitry. When this signal recombines with the processed aural signal, impairment of the received aural signal will result. This impairment could result in a substantial reduction in the amount of separation between the left and right channels. More testing needs to be conducted to confirm or dispel this concern.

One processor measured had 2% AM on the FM sound carrier with 25kHz deviation and 16% AM with 70kHz deviation. This would clearly cause a problem when using analog descrambling information on the aural carrier.

In addition to the notch problem, the 3dB bandwidth of the sound path was measured on one type of processor to be approximately 350kHz. No attempt is made to control delay characteristics at the band edge. One member of the Committee described the use of unequalized filters in home stereo receivers. This practice results in stereo separation of 40dB, a number considered adequate. General practice has been to control amplitude characteristics of filters, but no special care is used in controlling delay characteristics. This practice has not been reported to have caused any problems of which the Committee is aware.

In general, the NCTA Subcommittee believes IF circuitry in all existing processors would have to be redesigned for successful MCS operation.

b. Modulators

If external MCS signals are generated and pre-emphasis circuits are removed from modern modulators, it may be possible to use them for MCS transmission without difficulty. Older designs may have problems caused by transformers used for coupling and uncontrolled amplitude and phase characteristics in filters.

c. Demodulators

Volume I of the referenced MCS report discusses the impact MCS will have on TV receivers; since most demodulators use similar circuitry, they will experience many of the same problems. This includes insufficient sound IF bandwidth, problems with buzz caused by intercarrier sound processing and inadequate baseband response to pass MCS subcarrier components.

3. Set-Top Converters(Scrambling/Descrambling)

Of all the possible problems, this one has the potential for the greatest impact on the CATV industry. Devices with the greatest proliferation use either pulse or sinewave sync suppression. Problems with both systems can arise when FM to AM conversion occurs in headend processors, modulators and set-top converter bandpass filters. These products manifest themselves in different ways. In the case of pulse systems, the AM pulse on the sound carrier, and any spurious AM products, fire a trigger circuit, usually a monostable multivibrator. Any stray AM products or noise can cause descrambling pulse jitter due to slicer uncertainty.

An attempt was also made to simulate stereo susceptibility to stray tagging and descrambling pulses. Measurement data seems to indicate compatibility between MCS and pulse scrambling systems; however, reports from the field indicate buzzing is being experienced on some sets imported from Japan which include stereo demodulator circuitry using the Japanese standard. These reports must be investigated prior to reaching any final conclusions.

The sinewave sync suppression system may be most susceptible to FM to AM conversion products. These systems will undoubtedly suffer from the almost certain increase in AM products on the aural carrier. Additional testing is to be performed in this area by the Subcommittee.

Several manufacturers have baseband systems in the field. Since these units have demodulators, the performance and problems will be similar to those experienced with TV sets. Special MCS units will likely be similar to the tuner, IF amp and detector circuitry developed for TV receivers intended for MCS operation. This suggests units already in the field can continue to be used for subscribers with monophonic TV receivers, while units of a new, compatible design would be required for subscribers wishing to avail themselves of the opportunity to have multichannel sound. The one unknown, to be investigated, was discussed earlier in section B.1. of this report. The adjacent channel sound traps in these products could be expected to behave like those in TV sets. One manufacturer uses crystal stabilized local oscillators with AFC and SAW IF filters. When compared with older tube-type television sets with unstable IF circuitry, these units may offer satisfactory performance. This must be verified before concerns can be relaxed.

D. Phase Noise Considerations

In Volume I of the Multichannel Sound Report, mention was made that a return to split-sound TV receiver design could eliminate sound buzz due to incidental phase modulation of the sound carrier generated by mixing with the video carrier. This would certainly be the case; however, all concerned must also recognize there are additional problems created by this technique which will likely be made worse by equipment presently used in cable systems. Indicated below are several areas which need additional investigation before split-sound receiver design should be considered.

1. AML Equipment

On page 161 of Volume I of the MCS report, the EIA Committee discusses a problem with translators in Japan. "During the rebroadcast tests of MCS signals, a large increase in buzz interference within the subchannel was observed. The interference was especially noticeable in split-carrier reception. This was due to amplitude and phase nonlinearities of traveling-wave tube (TWT) power amplifiers used in old translators and also due to cascaded use of such translators." There is reason to believe a similar problem may exist with AML equipment. Tests are underway to determine what impact this equipment will have on future TV receiver design.

Although most operators use phase locked receivers for AML transmission, some operators occasionally use receivers with free running local oscillators. In such cases, the levels of IPM increase substantially. One cable operator measured substantial increases in noise levels using these receivers with synchronous demodulators. MCS TV receivers using split sound systems would experience impaired noise performance as a result of this phenemonon.

2. Headend Equipment

Most signal processors and modulators use oscillator designs which are crystal controlled; however, there are presently on the market several multichannel units (typically used for standby purposes) which use oscillators that are either frequency synthesized or under AFC control. These devices will almost certainly increase the amount of incidental phase modulation present on the sound carrier.

3. Set-Top Converters

Converters which use synthesized tuning systems introduce substantial levels of incidental phase modulation (ICPM) on the TV signal. Older varactor tuned products also introduce ICPM, but to a lesser degree. TV receivers using intercarrier sound detection are not affected by high levels of ICPM when both the visual and aural carriers are subjected to the introduction of ICPM: however, in TV receivers using split sound IF and detection systems ICPM products introduced by CATV converters can contribute to deteriorated noise performance. It is not uncommon for varactor converters to introduce frequency modulation on the TV signal in excess of 10kHz. This suggests a serious problem for the cable industry if split sound TV receivers are introduced in the marketplace.

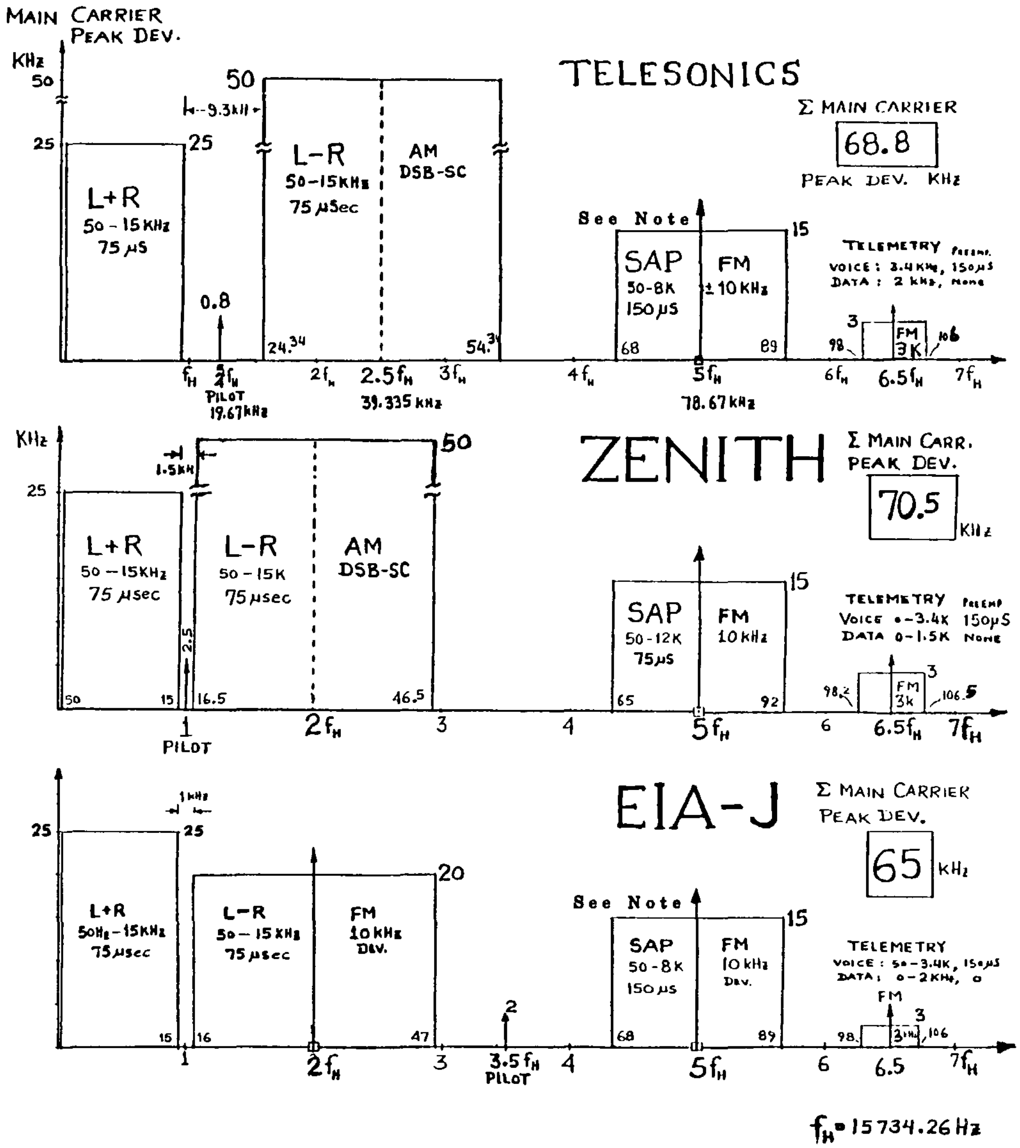
SOME ADDITIONAL THOUGHTS ON MULTICHANNEL SOUND

One must ask if the course of action the television industry is about to embark on is appropriate now. We are introducing 40-year old technology at a time when a quantum leap in digital technology is about to take place. The TV sound system in the United States is already being strained to capacity with performance which can best be described as marginal. The course of action we are about to embark on appears to take a marginal situation and make it worse. This action is taking place at a time when the telephone industry is moving in the direction of digitized voice communications, at a time when the consumer stereo industry is on the verge of moving away from the traditional analog methods into digital technology using laser disks and tape, and when satellite delivery mechanisms such as Public Broadcasting Service (PBS), Home Box Office (HBO) and Direct Broadcast Satellite (DBS) services are moving to digital audio.

The CATV industry is facing some serious problems with the present methods of premium program security. Our premium TV security systems face serious threats not only by tampering but also by units manufacturered and sold on the black market. The industry is also facing pressure in the regulatory and legislative area to make the sound on certain channels unavailable to the owners of cable-ready sets and users of conventional converters. The task of keeping our premium signals secure eventually may come to depend on scrambled digital audio. If the TV industries could successfully develop standards for digital stereo audio which are compatible with the existing monophonic system, then a quantum leap will have been realized which would be a direct benefit to the American viewing public. It will be a challenge to develop cost-effective digital technology compatible with the TV sound system already in place, but engineers using the latest technology have the capacity to overcome difficult challenges. It is true there are difficult compatibility issues to be overcome, but this is a real opportunity to enhance the quality of television in the United States.

CONCLUSION

This paper has described several major elements in CATV systems where the carriage of multi-channel sound might create problems. At the time of this writing the NCTA Engineering Committee has outlined a test plan to investigate these topics. The tests, which began in February and will last about six months, will be performed by representatives of the cable industry working in conjunction with EIA Committee engineers. The results will be described in a comprehensive report including both subjective and objective evaluations of each area of concern. If testing results are negative, it may be appropriate for the industry to lead the drive to develop standards for a digital audio system.



Rev. 5-18-82
4-15-83

Note: Telesonics SAP Changed to 50-10k 75μs

EIA-J SAP Changed to 50-12k 75μs

Figure 1

Baseband Spectra (Proposed Systems)

Source: Multichannel Television Sound, Volume I, p. 57

THEATER STEREO FOR THE HOME

Richard M. Wolfe

Twentieth Century-Fox Telecommunications

Stereo simulcasts for certain television programs via FM radio, both direct and over cable, have been done for many years. Video cassettes and video discs now provide an additional source of stereo sound for television in the home. Up to now, such stereo has been two channels (left and right) only. Thirty-five millimeter motion picture stereo is presently four-channel stereo. Today a technique exists to transmit four channel theatrical stereo into the home via any cable, FM broadcast, or home video delivery system. By use of a special Dolby Stereo decoder, the four channels can then be recovered which provides audio quality and realism equal to or better than that obtainable in the typical motion picture theater of today. With a large screen TV this system can truly convert television viewing into the stereo theater of the home.

In 1953, 20th Century-Fox released the first motion picture in Cinemascope with stereophonic sound. This sound was recorded using four separate magnetic soundtracks and released on prints which were equipped with four magnetic stripes running along the film located inside and outside the film sprocket holes. These four tracks were recorded with sound designed to be played back over three large speaker systems behind the screen, and a group of smaller speakers located in the rear of the theater. The three screen speakers were arranged with one in the center, one on the left, and one on the right. In this way, the location of the sound source could be made to match the location of the picture action across the screen face using sound from three of the tracks. The fourth track contained a rear "surround" channel designed to be played back over a "curtain" of speakers all connected together and placed around the rear and side walls of the theater. This surround channel was used to provide ambiance, or reverberation for music, and for many special off-screen effects such as thunder, rain, airplanes, explosions, and the like.

This theatrical stereo technique became quite successful and was used for a number of major films in the years following THE ROBE. There were problems however. The magnetic striping and real time recording on release prints was expensive, and playback headware and system alignment in the various theaters around the world required frequent attention and maintenance. Many theaters complained about these problems and in the early 1970's Dolby Laboratories, whose name today is well known for the development of audio noise reduction systems, began the development of a new theatrical stereo process to try to solve these problems. The Dolby stereo development incorporated two major concept changes as compared to the discreet four-track magnetic system. The first was the use of a stereo matrix process. This matrix technique involves combining the four left, center, right, and surround signals into a two-channel encoded signal, which then contains all of the information present in the original four signals, but requires only two recording channels rather than four. The second was the development of a two-channel optical recording device so that two high quality optical soundtracks could be placed on the release prints in the space previously occupied by the single monaural optical track, in use since the beginning of motion picture sound. This improvement meant that this two-channel optical track could be printed onto release prints during normal laboratory picture printing and developed as part of the picture processing and development, a process revision that eliminated the cost of magnetic striping and recording each print.

Theaters were then equipped with compatible two-channel optical playback readers which could read both traditional mono tracks and the new Dolby stereo optical twin tracks interchangeably. In addition to the two-channel optical reader, the projection rooms were also equipped with a matrix decoder to unscramble the two-track audio signal back into the original four discreet signals: left, center, right, and rear surround.

The Dolby theatrical matrix system is analogous to the CBS/Sony SQ or Sansui QS "Quad" systems for home stereo of some years ago, but the Dolby encoding/decoding system is somewhat less complex. With Quad, two channels are used in front and two channels are placed in the rear of the listening environment. This gives a listener the ability to hear an apparent sound source in a 360 degree horizontal location around the listener. The Dolby technique relocates the channels, with three channels in front, in the plane of the visual action, and one channel in the rear. This speaker placement concentrates the sound in the picture area while still allowing some source of sound from the rear. The Dolby speaker locations do not allow specific localization of sounds at various points across the rear or along the theater side walls, but is intended to give the primary sound focus across the screen. Dialogue, however, is place only in the front center channel. This helps to minimize crosstalk with the rear, where dialogue is undesired. A time delay circuit is also incorporated in the rear channel to further minimize crosstalk in the rear channel. The rear signal is delayed so that any front channel signal will arrive at a viewer's ears at least 30 milliseconds before a signal from the rear. The Haas effect then insures that rear channel crosstalk will be undiscernible.

The Dolby theatrical stereo system also makes use of the noise reduction systems for which the company is best known. The two encoded channels are recorded with the professional A type system on the optical track giving a signal to noise ratio of about 60 db and optical galvanometer improvements provide a flat frequency response from about 20 Hz to beyond 15 kHz. This is a great improvement over traditional mono optical soundtracks which are limited to about 8 kHz in 35mm and about 5 kHz in 16mm. In order to further minimize unwanted noise from the rear surround channel speakers, which are often quite close to the ears of viewers located in the rear of the theater, and which frequently have "no signal" conditions, the additional use of a modified form of the home B type noise reduction is used as well to further suppress the noise in this channel.

To date, over 400 titles have been released using the 35mm Dolby stereo process and many have also been released in the 70mm format with six channel discreet stereo, which continues to utilize magnetically striped prints similar to the old 35mm format but with six tracks instead of four. Stereo continues to be a popular release format and more and more pictures continue to be released in this form each year.

Feature motion pictures have been transmitted over television since television began in the late 1940's. The traditional film medium of supply was the 16mm print which, while it produced a usable image, has a monaural optical soundtrack of very limited frequency response, high noise and high distortion; definitely lo fi and non-stereo. When cable came along, the 3/4" U-matic cassette, usually made from the same 16mm prints used by TV stations, became the standard for those systems who wanted to originate their own movie showings. These again were lo fi, mono, and had a poorer quality picture than even the direct projection of 16mm film.

Today, however, things are changing. The recent advent of stereo VHS and Beta cassette recorders and of the Laserdisc and the RCA CED videodisc with high quality stereo audio have created a demand for motion picture in the home with high quality stereo sound.

The decision of MTV and The Movie Channel to transmit much of their programming in stereo creates additional demand for stereo film product. And, when the FCC approves stereo audio for television broadcast stations, the demand for stereo movies will again increase. It is also reasonable to assume that the other national pay movie services like HBO, Showtime, Disney, and local originators as well, will also convert to stereo transmission at some point in the near future.

Since the advent of the 35mm Dolby matrix stereo system, almost all of the major studios have been producing 35mm encoded mag track masters,containing the two matrix soundtrack signals, which are used to create a two-track Dolby optical printing negative. These matrix encoded mag tracks have a compatibility feature such that if they are played over a normal two-channel left and right stereo system, they will produce excellent two-channel stereo. The hidden, or encoded, center and rear surround channels are just not recovered. But, if the two-channel signal is played through a matrix decoder, the center and rear surround signals can be heard and the full four-channel theater sound recovered.

For the past two years, 20th Century-Fox, and some of the other major studios, have been using Dolby matrix encoded mag track masters as the sound source for master videotape transfers of stereo film features. These video masters are then used as the source of pay TV, home video, and syndication tape and disc copies. This means, of course, that matrix encoded stereo is now and has been available to many home viewers, even though this fact has not been widely publicized.

While Dolby Labs do build matrix decoder systems for professional and theater applications, they do not manufacture units for home use. They have however licensed a company known as Surround Sound, Inc., in Santa Monica, California, to produce a home matrix decoder using a circuit of Dolby design. This Surround Sound unit is a scaled-down version of the Dolby theater system. It has been greatly simplified by the deletion of any gain shifting electronics and the elimination of a center channel output. It does have however a self-contained 20-watt power amplifier to feed the rear surround speakers and the proper decoder circuitry to produce left, right, and surround channels. The unit also includes an appropriate rear channel delay line and Dolby type B noise reduction circuitry. The system is quite satisfactory for use with a typical TV set or monitor when used in a normal sized viewing room where the rear speakers are not more than about 30 feet from the TV screen. The absence of a center channel is a disadvantage with large screen projection systems, but several other companies are now in the process of development of decoder units of a more sophisticated form. Audionics of Oregon in Portland, who make high end audio components, are working on a full four-channel unit with gain shifting, and Jensen Sound Labs of Chicago, who make high end component TV systems, are also developing a similar system. Fosgate Research of Prescott, Arizona, presently has on the market a high quality decoder that, while designed primarily for the SQ system, can also be used to decode Dolby matrix surround. This unit does have gain shifting, but no rear channel delay circuit.

The effect of using surround stereo with television viewing is a striking improvement in realism. It truly converts TV watching into a new experience much closer to the experience of the theater. Instead of looking into the action from a separated location, the viewer becomes a part of the action environment; a technique that theaters have been using for years. Since excellent software product of this type is now available in any home video store, and the decoder hardware is now becoming readily available in the high fi and stereo equipment shops in the country, the public is starting to experience the tremendous improvement possible from this next step in home viewing technology. Since satellite, MDS, and cable can easily transmit the matrix stereo format and delivery to the home by FM cable simulcast is an easy and already used technique, there is no reason why cable cannot easily compete with the kind of home stereo being offered by both the theaters and the home video product of today.

THEORY, DESIGN AND APPLICATIONS OF MULTIPLE FEED SYSTEMS FOR PARABOLIC REFLECTOR ANTENNAS

James B. Grabenstein
Senior Applications Engineer

MICRODYNE CORPORATION

With programming source availability changing, real estate restrictions and cost effectiveness in mind, the satellite communication industry has generated the requirement to obtain service from more than one satellite into the same TVRO system. To achieve this goal, additional feeds have to be added to the existing TVRO system or the antenna changed to another type.

This paper is an attempt to outline some of the advantages and applications in changing to a multiple feed system on a parabolic antenna reflector. It covers some of the theory and math that has been incorporated into a computer program that is used to predict the gain and noise generated when the feed point is shifted from normal boresight. This paper will cover some of the data gathered from an extensive testing program that has been done on the multiple feed system in the field. The predicted data and field test data will be compared and analyzed.

The introduction of communication satellites into geostationary orbit has been a revolution to the communication industry. The major impact on the cable television industry has been the availability of revenue producing premium programming. One of the problems with this programming is that not all of the programming originates from the same satellite. We can be assured that this programming will be in constant change for competitive and economic reasons.

As a solution to the problems, the communications industry has asked for a method of adding multiple feed systems to existing antennas. This request is based on sound reasoning; real estate is valuable and hard to obtain for multiple antenna farms and these multiple antenna farms are costly. Today five satellites transmit video signals used by the cable television industry and many more are planned in the next few years. Other services are planned and are being promoted and will require looking at other areas of the geostationary arc.

Over this whole area of requirements looms the unanswered question, what about 2° spacing? One thing I want to state here is that by adding a multiple satellite feed system to a parabolic reflector is not the answer to all of your prayers. It is a tool and your knowledge of this tool and its application depends on the success of the use of a multiple feed system.

A satellite receiving antenna contains two functional parts, the reflector and the feed. Two types of reflectors are used in todays satellite receiving antennas. They are parabolic surfaces and speherical surfaces. The basic difference geometrically of these two reflecting surfaces, is that a spherical surface beam will eventually cross somewhere in space where in a parabolic reflector the beam will remain parallel to infinity. The widths of the beam and the patterns generated by the reflecting surface is determined by three basic functions. The first being the diameter of the reflector, the focal length of the reflector and the frequency in which the reflector is operated. The transformation of the pattern from theoretical to actual depends primarily on the reproduction of the accuracy of the surface in production methods. Most multiple feed antennas in use today that looks at large portions of the geostationary arc are designed around a spherical surface. The spherical surface is less efficient but blends itself easily to multiple focal points. The parabolic reflector has been used as a reflecting surface for satellite communication antennas because of its high efficiency. For that reason, we will address the use of adding additional feeds to the parabolic reflector in this paper.

The most efficient microwave receiving antenna known today is the antenna commonly called a sugarscoop or conical horn. These are offset feeds on a parabolic reflector with high shielding into the focal point producing very low noise and very accurate and predictable patterns. The problem with this type of an antenna is that it is quite costly but in some cases has to be used in the high terrestrial interference environments. The parabolic antenna is an economic antenna to produce and is the most popular in the cable industry today. Adding a multiple feed system to this antenna requires a certain amount of calculations that are predictable and some pattern characteristics that are extremely difficult to predict.

Two basic types of feed systems are used in todays satellite receiving antenna systems. One feed system is the cassegrain feed which requires a subreflector somewhere in the focal plain of the antenna. The other is a prime focus feed and the prime focus feed is a method in which the feed is located at the focal point of the reflector and is aimed at the surface and illuminates the surface evenly just inside of the reflecting surface. When a cassegrain type feed in in an antenna, it has to be removed and replaced with a prime focus feed when the reflector is to be used as a multiple feed system. A conical horn antenna by its design cannot be altered in any way for use as a multiple feed system.

To add a multiple feed system to a parabolic reflector, the geometric functions of the satellite's orbit position to the physical center of the reflecting surface and the focal length of the reflector must be considered. (See Figure 1)

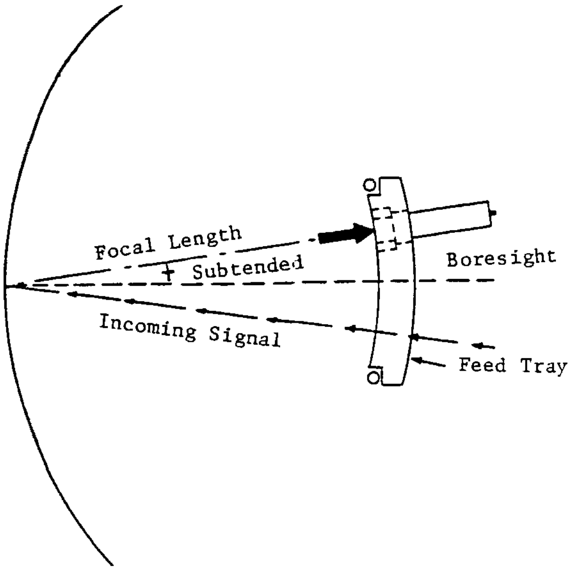


Figure 1

You will note that we treat each satellite as a single beam, the reflector as if it has one point of reflection, to set the angles of the feed in respect to boresight of the reflecting surface. This allows the feeds to be preset for their respective satellite.

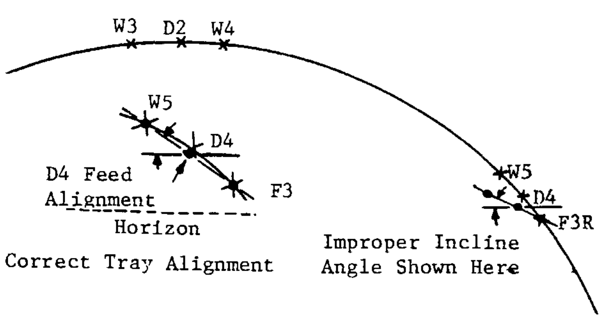


Figure 2

In Figure 2 the geostationary arc changes as it is viewed from different coordinates on earth for each satellite. The sector of the arc generated by the satellites of interest creates a chord that is the incline angle of the feeds. This focal incline angle is predictable and matches the chord between the arc of the extreme satellites. As long as this chord is less than 16 degrees, the satellites of interest will remain in the aperture of the feed system.

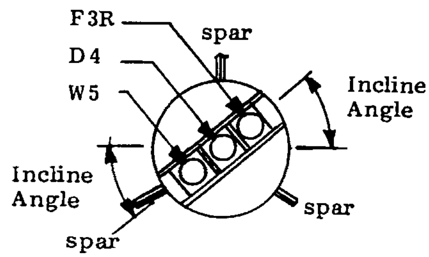


Figure 3

You will note in Figure 3 that the D-4 satellite will be slightly off of the chord of the geostationary arc. These calculations are predictable and usually do not affect the overall operation of the system. The prime consideration of aligning the feeds and the antenna is making sure that the chord of the geostationary arc lines up with the incline angle of the focal plane of the feed. You will also note in Figure 3 that the reflector acts as a mirror image and reverses the angles and the relationships of the satellites.

The relationship of the total gain of the antenna is predictable based upon the antenna diameter, the focal length of the reflector and the type of feed on the antenna. If the antenna is lined up on boresight and the feed placed in a position on that boresight, the gain of the antenna will perform the same as any normal antenna. As you move the feed from boresight, there will be a degrading of the gain of the antenna on a predictable gain loss curve. (See Figure 4) As you move from boresight, the gain of the antenna derates but you will note by Figure 4 that the noise generated within the antenna does not increase appreciably and in fact, you may note that it decreases as you move a couple of degrees off of boresight. The overall carrier to noise of the antenna does increase slightly.

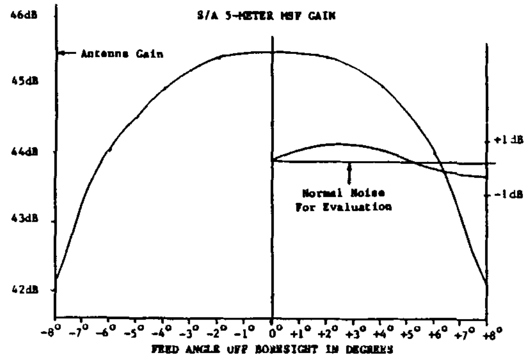


Figure 4

The side lobes of an antenna are the products of the total energy from the reflector not absorbed by the feed and the phase relationship of the electro-magnetic microwaves as they refract from the angular surface of the reflector. As the feed is moved from boresight, these phase angles change causing the level of the side lobes to vary in respect to the boresight gain of the antenna.

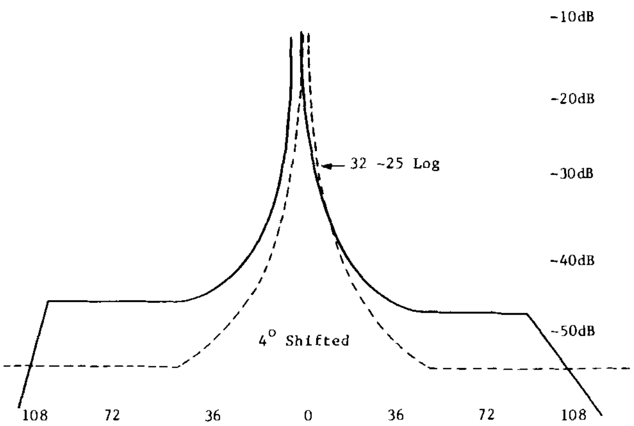


Figure 5

You will note in Figure 5 that the smoothed curves of the antenna radiation pattern degrades as you pull the feeds away from boresight. The side lobes of the antenna become very erratic as you move the feeds away from the boresight of the antenna. For that reason, if you have heavy terrestrial interference, it is not recommended that you try to use an off boresight fed antenna for a multiple satellite feed system. These patterns could be calculated for each angle but the problem is that the calculations would take many days of range time for each antenna system and could be quite costly.

As I mentioned at the beginning, a multiple feed antenna system connected to a parabolic reflector is a tool. This tool has a place in the communication industry, if you need an inexpensive way to view a couple of satellites or if you need a temporary feed system until you find out where the satellite spacing is going to settle. The multiple satellite feed system on parabolic reflectors will lose gains as you move from boresight, but it is predictable. The noise does not increase in some catastrophic manner. The side lobes change but not enough to cause major problems with todays satellite spacing.

The mathematical computations for the angles and spacing of the feeds is covered well in Norman Weinhouse's[1] paper. As a convenience, we have put this into a[1] computer program. This information is available to anyone wishing to run calculations for a particular location in the United States.

If you need a feed system to meet todays needs, don't be afraid to use it.

References: Norman Weinhouse, "Multiple Antenna Feeds"

Thanks to: Jerry Thorne, Microdyne Field Service
Robert Smith, Microdyne Field Service

THERMAL NOISE REVISITED

Dr. Harold W. Katz

STERN TELECOMMUNICATIONS CORPORATION

The calculation of the noise figure of a cascade of N unity gain sections is based on the formula NF where F is the amplifier noise figure. A more detailed analysis indicates that this formula is only an approximation. A more exact representation includes the noise figure of the passive elements (coax, taps, etc.), as well as that of the active components. The noise figure of a coax cable is shown to be equal to $1/L$ where L is the attenuation of the passive component. The calculation of the thermal noise for forward and reverse transmission of a cable network is made more precise through the consideration of the noise figure of a matched passive element. In addition to providing a more complete understanding of system noise figure for nonunity gain configurations, the resulting formulation also provides an opportunity for introducing additional parameters in the design of cable networks.

INTRODUCTION

The design of cable systems continuously involves, among other issues, calculations of accumulated noise. The interest in this subject is becoming much greater as larger systems are planned to provide both downstream and upstream transmission of data, audio, and TV for new services. The generation of upstream noise presents a new set of problems for the system designer as compared to the usual treatment of downstream transmission. The objective of this paper is to provide a review of some of the fundamentals of these noise calculations, and to show the advantage of a more unified method of calculating the noise for different configurations of amplifiers, taps and cable. Particular attention is given to the use of a noise factor for the passive as well as the active elements of the network. This method leads to a more exact formula for the noise accumulation of unit gain cascades, and trunk bridger/extender links.

NOISE SOURCE

The noise that appears in a cable network is generated by several different sources. The thermal noise of passive and active components, the ingress of undesired radiation external to the system, the generation of excess noise by the devices connected at each drop, and the intermodulation noise due to nonlinearities in the system are among the most significant components. For the purposes of this article, attention will be directed to the analytic foundation associated with the calculations of the thermal noise build up.

The thermal noise is attributed to the random motion of charge carriers in the resistive elements of the network and to the fluctuations in the currents within the active devices. The noise voltage generated by a resistor at a given temperature can be calculated directly from the value of the resistor. The contribution to the noise from the active devices is, however, generally determined from a measurement of the amplifier noise characteristics (i.e. noise factor or noise figure) rather than a detailed calculation based on a model of the internal noise sources.

The noise generated by a resistor R at temperature T is described by the equivalent circuit shown in Fig. 1. The noise source is considered to be a generator in series with a "noiseless" resistor R. The <u>open circuit</u> RMS voltage e_n is derived from the well-established formula,

$$\overline{e_n^2} = 4KTBR \tag{1}$$

where
K = Boltzman's constant
T = Absolute temperature
B = Measurement bandwidth

Another parameter defined for the resistor is the maximum available noise power which can be delivered to a load. The maximum power condition occurs when a matched load R is placed across the original resistor. From the simple circuit shown in Fig. 1b the noise power delivered to the matched load is the familiar value.

$$\overline{e_n^2}\ /4R = KTB \tag{2}$$

Equation (1) can be used for calculating the output noise power in circuits containing multiple resistive components. For example, the matched load resistor in Fig. 1b also serves as a generator of noise. Figure 2 shows the inclusion of a second noise generator whose maximum available power is also KTB. The output noise voltage across terminals a-b is calculated from $\overline{e_{nt}^2} = \overline{e_{o_1}^2} = \overline{e_{o_2}^2}$ where e_{o_1} and e_{o_2} are the noise voltages due to each noise generator. This procedure is valid since the equivalent noise generators are uncorrelated. For the circuit in Fig. 2 the result would be $\overline{e_{n_t}^2} = 2KTBR$.

The important point of this exercise is that the "available noise power" of a device is not necessarily the noise power that would appear across the output terminals when the matched load is actually placed across the device unless the load is assumed to be "noiseless".

The calculation of the maximum available power from a more complex array of passive and active components follows the same procedure. A general two-port device is shown in diagram Fig. 3a. The objective is to define a parameter which would characterize the output noise power that would be delivered to a matched load as shown in Fig. 3b. A known noise source (usually a resistor) is placed at the input terminals. The maximum available output noise power is then calculated. If the input of the network is matched to the resistor, the input noise power is KTB. The total maximum available output noise power is given by

$$N_o = FGKTB, \text{ where} \tag{3}$$

G is the maximum matched power gain or <u>loss</u> of the network, and F is the "Noise Figure" of the network which is related to the excess noise added by the network. The output power, N_o, consists of the contribution due to the external resistor, GKTB, plus the network noise N_m, i.e.,

$$N_o = GKTB + N_m = FGKTB \tag{4}$$

or

$$N_m = (F-1)\ GKTB \tag{5}$$

If two matched networks are cascaded as shown in Fig., 4, one can use the same approach to obtain the usual formula for the effective noise figure, F_e, for the cascade which is defined in the following equation:

$$N_o = F_e G_1 G_2 KTB \tag{6}$$

where N_o is the total maximum available noise power at the output of the network if the input noise is due to an external resistor. At the junction of the two matched networks, the noise power input to the second network is $F_1 G_1 G_2 KTB$. From (5) the contribution of the second network to the output noise is:

$$(F_2-1)\ G_2 KTB \tag{7}$$

Therefore,

$$N_o = F_1 G_1 F_2 KTB + (F_2-1)\ G_2 KTB \tag{8}$$

$$\text{or } F_e = F_1 + \frac{F_2-1}{G_1} \tag{9}$$

For a cascade of n stages, one obtains the familiar formula

$$F_e = F_1 + \frac{F_2-1}{G_1} + \frac{F_3-1}{G_1G_2} + \ldots + \frac{F_n-1}{G_1\ldots G_{n-1}} \tag{10}$$

Equation (10) is normally discussed in detail for networks containing active components each with their respective noise figures and available gains.

<u>MATCHED PAD NOISE FACTOR</u>

The concept of a noise figure is, however, equally valid for matched passive networks. Fig. 5a shows a symmetrically matched pad which introduces a fixed loss L, i.e., its power gain G = 1/L measured from terminals a - a' to b - b'. To find the noise figure of a matched pad, use the equivalent network as shown in Fig. 5b where a noise generator has been added for each resistor in the network. All of the resistors are assumed to be at the same temperature.

The open circuit noise voltage V_{oc} due to each generator are calculated separately. The maximum available output noise power is then equal to $V_{oc}^2/4R_o$ for each generator. The results are summarized in the following equations:

For generator e_o:

$$V_{oc} = e_o R_3 /R \tag{11a}$$

where $R = R_o + R_1 + R_3$

$$P_o = GKTB \quad \text{where } G = \frac{R_3^2}{R^2} = 1/L$$

For generator e_1

$$V_{oc} = e_1 \, R_3/R$$

$$P_1 = GKTB \, R_1/R_o \tag{11b}$$

For generator e_2

$$V_{oc} = e_2$$

$$P_2 = KTB \, R_2/R_o \tag{11c}$$

For generator e_3

$$V_{oc} = e_3 \; (1 - R_3/R)$$

$$P_3 = \frac{KTB \; R_3^{\,2} \; (R_o + R_1)^{\,2}}{R^2 R_o} \tag{11d}$$

The total output noise power is then

$$N_o = P_0+P_1+P_2+P_3 = FGKTB \tag{11e}$$

where F is the noise figure of the pad

Since the pad is matched $R_1 = R_2$, and therefore

$$R_o = (R_o+R_1)\ \frac{R_2}{R} + R_1 \tag{11f}$$

If the substitutions are made in (11e), then

$$N_o = KTB, \tag{12}$$

and therefore FG = 1.

Since $G = {}^1/_L$,

$$F=L \tag{13}$$

In other words, the noise figure of a matched pad is exactly equal to its loss. The output noise power is just equal to the input noise power, even though the input noise power is attenuated by a factor $^1/_L$. The additional output noise is contributed by the noise generators within the pad as shown by the terms P_1, P_2, and P_3 in equation (11e). It is also interesting to observe that if the temperature of the pad was at absolute zero, then $P_1 = P_2 = P_3 = 0$. For this case, $N_o = KTB/L$, and $F = 1$. The output noise power of the pad is thus reduced by a factor $^1/_L$ compared to the case in which the pad temperature was equal to that of the input resistor.

COAX CABLE NOISE FACTOR

The result also applies to a coaxial cable. The internal resistors which provide the additional noise in this case are the distributed resistors of the cable rather than the lumped resistors of the pad. The derivation of the noise factor for the coax is perhaps more instructive than the one for the matched pad. Fig. 6 shows a transmission line with a noise generating resistor (R_o) at one end and a noiseless resistor (R_o) at the receiving end. For simplicity the cable loss is attributed only to a distributed series resistance equal to r ohm's per unit length. The calculation of the total noise power in the terminating resistor follows the same procedure as for the pad. The details are given in the appendix. The output noise power due to the resistor R_o is

$$N_1 = KTB/L, \text{ and} \tag{14}$$

the output noise power due to the cable is

$$N_2 = KTB\ (1-\frac{1}{L}), \text{ where} \tag{15}$$

$^1/_L$ is the power loss (G) of the coax.

The total noise power is, therefore,

$$N_o = N_1+N_2 = KTB=FGKTB \tag{16}$$

The noise factor for the coax is

$$F=L, \text{ since } G={}^1/_L \tag{17}$$

It should be noted that the relationship, F = L, for the pad and the coax is exact only when the temperature of these components is the same as that of the input resistor as assumed in the above calculations. Equations 11 and 16 can be suitably modified to include any differences in temperature.

DIRECTIONAL COUPLER NOISE FACTOR

The directional coupler is another important passive component whose noise factor must also be considered for the general cascaded network. A schematic of a three-port coupler is shown in Fig. 8. The output noise power consists of the input noise at port one, which is attenuated before reaching port two, and the noise generated by the terminating resistor at port three. The latter, however, is severely attenuated due to the directionality of the coupler. Hence the coupler, in the forward direction, reduces to the matched pad case. Therefore, the noise factor from port one to port one two is $F = L_1$, the coupler loss factor.

NOISE FACTOR OF CASCADED AMPLIFIERS, TAPS, AND CABLES

With the preceding argument, it is now relatively straight-forward to calculate the effective noise figure for diffirent configurations of amplifiers, taps, and cables that are encountered in a cable network. It will also be possible to note where simplifying assumptions have been made in the standard formulas used for cascaded networks.

A) Tandem Amplifier and Coax

The effective noise figure for Fig. 9 from eq. 10 is

$$F_e = F + \frac{L-1}{G} \quad (18)$$

where F = noise figure of matched amplifier

G = available power gain of amplifier

L = loss factor of the cable

A standard cable network design uses L = G, i.e. unity gain sections.

For this case, $F_e = F+1 - 1/_L$ (19)

The important case of a cascade of N unity gain sections can be calculated by substituting eq. 19 into eq. 10. The result is

$$F_e = NF + 1 - \frac{N}{L} \quad (20)$$

This differs from the conventional formula by the added term 1-N/L. However, for practical situations in which $L \sim 100$, $N \sim 20$, and $F \sim 10$, equation 20 reduces to the commonly used formula

$$F_e = NF \quad (21)$$

The derivation of equations 19 and 21 shows the significance of the cable noise factor. As an extreme example, let us evaluate the noise factor of a cascade of unity gain sections when the amplifier is ideal, i.e. F = 1. Eq. 21 yields an effective noise factor of N, i.e. there is a noise buildup even with a cascade of ideal amplifiers connected by lossy cables. The role played by the cable noise is more evident in eq. 25 when F = 1.

A clearer picture of this idealized case can be obtained by tracing the noise through a single unity gain section. The input noise is KTB. The noise at the output of the ideal amplifier is GKTB, which is attenuated by 1/G in the coax, and appears at the output as KTB. If there were no other contribution to the noise, the succeeding cascades would always produce KTB at the output without any buildup. This would be the equivalent to the case where the cable had no noise (i.e., F = 1), but maintained its attenuation L. However, the cable does contribute an additional (1-1/L) KTB to the output noise as shown previously. In the practical case, however, of noisy amplifiers, the noise buildup is due primarily to the amplifier as shown in eq. 21.

B) Tandem coax and directional coupler

A typical configuration is shown in Fig. 10 with two lengths of coax connected by a directional coupler. Eq. 10 yields the effective cascaded noise factor

$$F_e = L_1 + \frac{L_2 - 1}{1/L_1} + \frac{L_3 - 1}{1/L_1 1/L_2} \quad (22)$$

$$= L_1 L_2 L_3$$

The network gain is

$$G = \frac{1}{L_1 L_2 L_3} \quad (23)$$

The available output noise power for this combination is

$$N_o = FGKTB = KTB \quad (24)$$

Therefore a cascade of matched taps and coax cable can be considered from a thermal noise viewpoint as the equivalent of a single coax with the same loss factor as the cascade.

C) Trunk with Bridger and Extenders

Another familiar configuration is shown in Fig. 11 in which a main trunk amplifier also contains a bridger amplifier to feed extender amplifiers for local distribution. The transmission path consists of unity gain sections in the trunk and extender sections coupled by a loss L between the trunk amplifier and the bridger. This latter factor needs to be taken into account in deriving the expression for the accumulated noise from the headend to the end of the extender. The system parameters in Fig. 11 are defined as follows:

G_T= trunk amplifier gain

F_T= trunk amplifier noise factor

L = loss factor trunk to bridger

F_B= bridger and extender noise factor

N_T= number of trunk amplifiers in the cascade (excluding the one containing the bridger).

N_B= total number of bridger and extender amplifiers in one extender leg

The noise factor of the trunk cascade from A to B is $N_T F_T + 1$. This is derived from eq. 20 assuming $N/_L$ 1. The noise factor of the trunk to bridger (points B to C in) is $F_T + L-1/G_T$. The noise factor of the extender leg from C to D is $N_B F_B + 1$. The effective noise factor F_e of the three regions in cascade is calculated from eq. (10).

$$\therefore Fe = N_T F_T + 1 + F_T + \frac{L-1}{G_T} + \frac{N_B F_B}{G_T \times 1/L} \quad (25)$$

$$\text{or } Fe = (N_T+1)\, F_T + \frac{L}{G_T} N_B F_B + \frac{L-1}{G_T} + 1 \quad (26)$$

The usual formula for Fe considers only the unity gain sections to yield

$$Fe' = (N_T + 1)\, F_T + N_B F_B \quad (27)$$

Eq. 26 approximates Eq. 27 only for the case where L=G, i.e. with a unity gain section between the trunk and bridger. The contribution of the bridger and extender sections to the downstream noise is reduced by the factor L/G. For the case in which L = 10 (10dB) and G = 100 (20 d B), L/G = 1/50. Therefore the effect of the bridger/extender section is even less than that calculated in the standard manner.

D) Branch Network

In the previous illustrations the noise factor was considered for simple paths in which thermal noise from other branches did not enter into the main path. The latter occurs when there is upstream transmission from many points to a single head-end location as shown in Fig. 12. The illustration contains a main trunk with bridger amplifiers driving extender amplifiers with taps distributed along the extender path. The calculation uses the same technique developed for individual sections, i.e. calculate the noise factor and gain for each path, and then calculate the noise at the end of the path due to a resistor at the beginning of the path using No = FGKTB. Where several paths join via a directional coupler, the noise contribution of each path is then added at the common point. A typical path is the last extender leg before the first return amplifier. At the last tap, the terminated drop cable generates a thermal noise power of KTB at the input to the tap which has a tap loss of $1/L_1$. The extender coax also generates KTB at the downstream side of the tap which has a through loss of $1/L_2$. At the upstream leg of the tap the total noise power would be KTB $(\frac{1}{L_1} + \frac{1}{L_2})$. However, under a previous assumption $1/L_1 + 1/L_2 = 1$. Therefore, the next section of extender coax generates KTB as the input to the next tap. Hence no matter how many drops there are on the leg, the input thermal power to the last extender amplifier (A) will be KTB. A tapped trunk section with no active devices on the taps, generates the same amount of noise power in the upstream direction as a cable with the equivalent loss. The noise factor F_1 for the unity gain sections from A to B is

$$F_1 = N_e F_e + 1, \text{ where} \qquad (28)$$

N_e = number of extender amplifiers (Excluding the bridger)

F_e = noise factors of extender amplifiers

The noise factor from B to C is

$$F_2 = F_e + \frac{L-1}{G_B}, \text{ where} \qquad (29)$$

L = loss factor between bridger output and trunk input

G_B = bridger power gain

The effective noise factor from A to C is therefore

$$F_E = (N_e+1)F_e, \qquad (30)$$

neglecting the term $1 + \frac{L-1}{G_B}$.

The return noise power at A due to the extender section is

$$F_E G_e KTB = (N_e+1) F_e \frac{G_B}{L} KTB. \qquad (31)$$

Except for a small correction factor, eq. 31 is also the noise power of the extender section at D, since the gain is one from C to D.

The upstream noise power due to a single trunk leg is $N_T F_T KTB$, where N_T is the total number of trunk amplifiers up to D.

The total return noise power is

$$(N_T F_T + n\, G_{B/L}\, (N_e+1) F_e) KTB, \qquad (32)$$

where n is the total number of extender legs connected to trunk. The factor $G_{B/L}$ controls the relative contribution of the extender legs to the upstream thermal noise.

CONCLUSION

The calculation of the accumulation of thermal noise in a broadband network is made more precise through the explicit introduction of a noise factor for the passive as well as the active components. When combined with the formula for the noise factor of a cascade of elements, it provides an accurate picture of the approximations that are made in applying the usual CATV thermal noise formulas. The use of a noise factor for a passive element is extremely useful in situations in which the cascade does not consist soley of unity gain sections. The resulting formulations provide an opportunity for introducing additional parameters for cable network designs.

APPENDIX

The noise factor of the coax cable is calculated from the equivalent circuit of a differential length of cable shown in Figs. 6 and 7.

At the transmitting end

$$\overline{e_{n_1}^2} = 4KTBR \qquad (1)$$

The noise voltage e_n appearing at the input terminals to the coax is $e_n = e_{n_1/2}$ (2)

The noise power into the coax is therefore KTB. If the coax has an attenuation coefficient α, then the voltage at the receiving end is

$$e_r = \frac{e_{n_1}}{2} e^{-\alpha}$$

except for a factor due to the time delay. The noise power developed across the terminating resistor is then

$$\overline{e^2_{r}}/R_o = KTB\, e^{-2\alpha \ell} \qquad (3)$$

∴ the power gain (loss) is

$$G = e^{-2\alpha \ell} = {}^{1}/_{L} .$$

The noise power due to the distributed resistor can be determined from the equivalent circuit shown in Fig. 7 where the two sections of the coax have been replaced by their input impedances R_o. A differential length Δx of cable at a distance x from the termination generates a noise voltage e_x where

$$\overline{e_x^2} = 4KTBr \qquad (4)$$

and the voltage e in Fig. 7 is $e_{x/2}$, since $R_o >> r$.

Hence the noise voltage (e_o) across the terminating resistor due to the noise generated at a distance x from the load is

$$e_o = \frac{e_x}{2} e^{-\alpha x} \qquad (5)$$

The noise power generated per unit length in the terminating resistor is

$$e_o{}^2/R_o = KTB \frac{r}{R_o} e^{-2\alpha x} \qquad (6)$$

The noise power due to the entire coax is

$$P = KTB \frac{r}{R_o} \int_o^{\ell} e^{-2\alpha x} d_x = \frac{KTB\ r}{2\alpha R_o} (1-e^{-2d\ell}) \qquad (7)$$

For low loss cable or at high frequencies it can be shown that the attenuation coefficient (1)

$$\alpha = \frac{r}{2R_o} \qquad (8)$$

Hence the total noise power from equation 16, 20 and 21 is

$$P_o = KTB = FGKTB \qquad (9)$$

Therefore the noise figure for the coax equals L as in the case of the matched pad, since $G = {}^{1}/L$.

REFERENCES

W.L. Everett, "Communication Engineering", McGraw-Hill, N.Y. 1937

W.W. Mumford and E.H. Schiebe, "Noise", Horizon House-Microwave, Inc. Dedham, MASS. 1968

F.R. Conner, "Noise", Edw. Arnold, London, 1973.

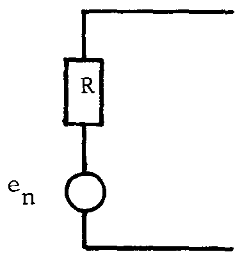


Fig. 1a

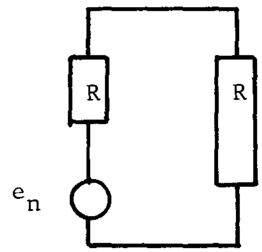


Fig. 1b

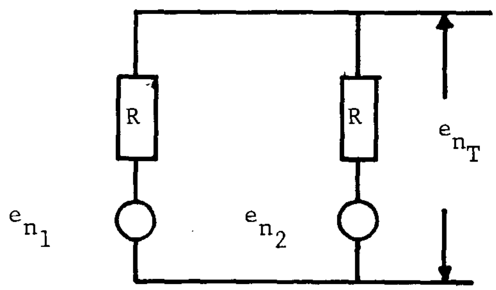


Fig. 2

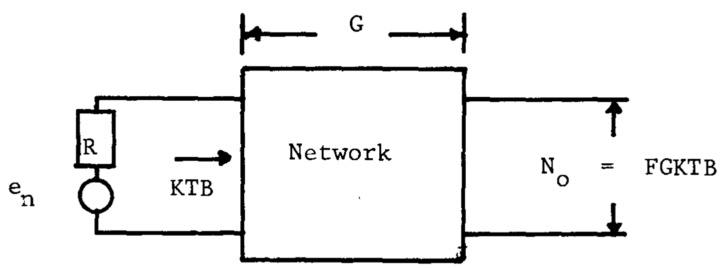


Fig. 3

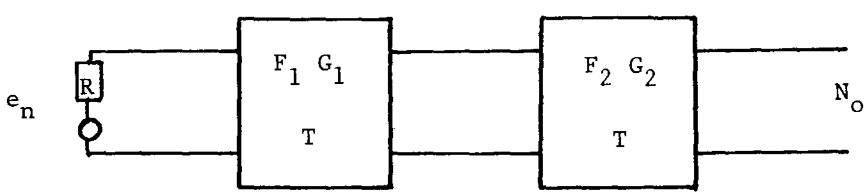


Fig. 4

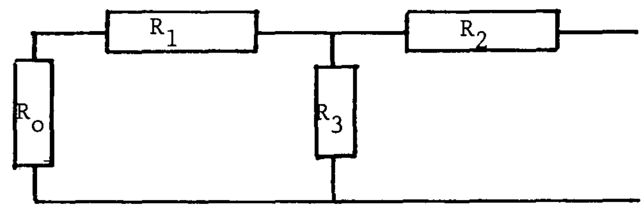


Fig. 5a

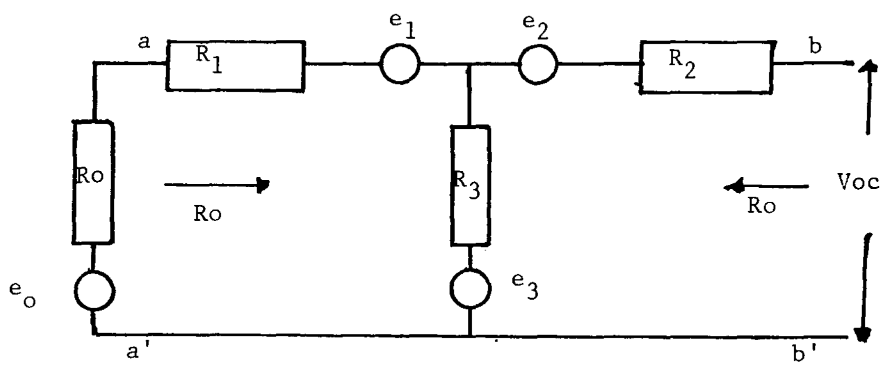


Fig. 5b

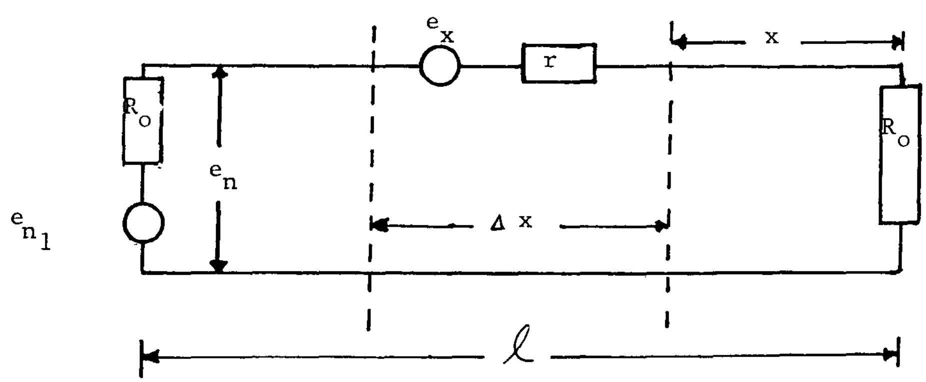


Fig. 6

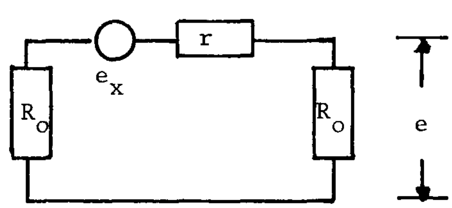


Fig. 7

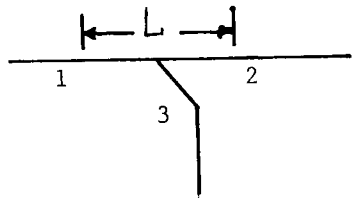


Fig. 8

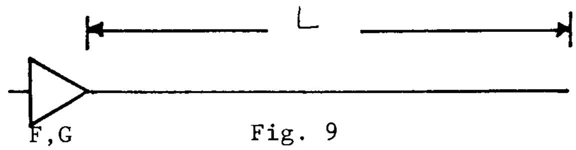


Fig. 9

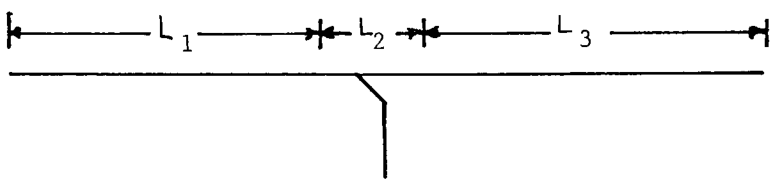


Fig. 10

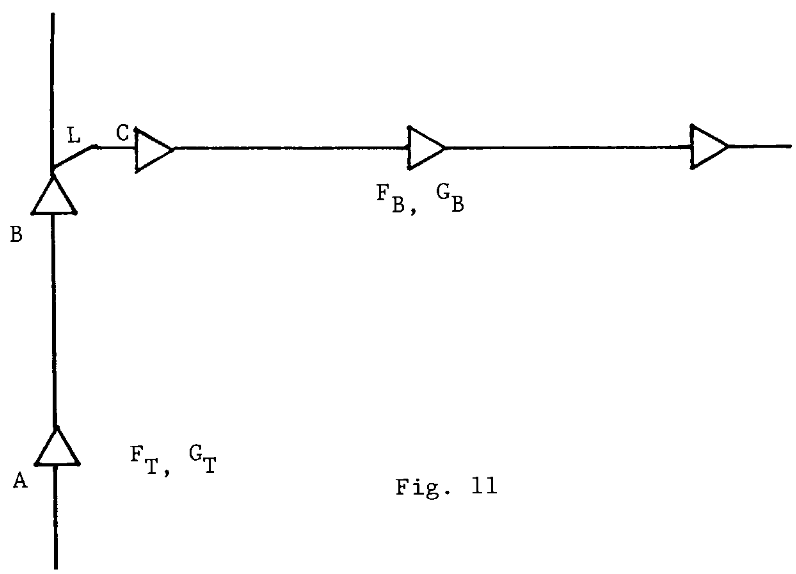


Fig. 11

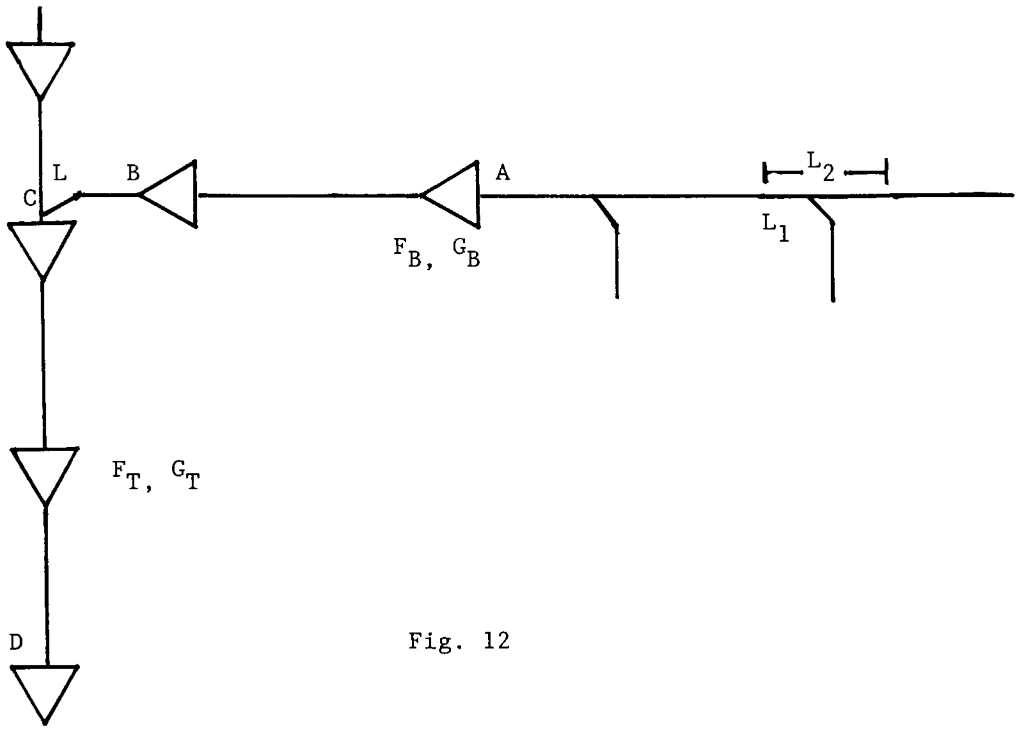


Fig. 12

TIME SELECTIVE SPECTRUM ANALYSIS
EXTENDING SPECTRUM ANALYZER'S USEFULLNESS

JOHN L. HUFF
STAFF ENGINEER

TIMES MIRROR CABLE TELEVISION

Spectrum Analysis of Radio Frequency Carriers modulated with video, can be made more comprehensive when the time of observation is assisted by a Video Waveform Monitor's timing circuits.

Anyone who has used a spectrum analyzer to observe a television modulated carrier, knows the difficulty in seeing through all the video signals clutter when looking for spurious signals. Spurious signals, V.I.T.S. and other video RF responses can be observed and recorded easily without interference from other ambiguous video signals.

The technique described in this paper will extend the utility of the Spectrum Analyzer and help provide information that was difficult or impossible to record using the previous techniques.

This paper will assume that you have a working knowledge of the Spectrum Analyzer and the Video Waveform Monitor.

THE APPROACH TO THE THEORY OF TIME SELECTIVE SPECTRUM ANALYSIS

The concept is over 10 years old with over five years of useful experience with an occasional new application using this technique.

I will confine this paper to useful application of Analysis of Cable Television signal carriers using Time Selective Spectrum Analysis.

The minimum additional basic equipment to perform the needed functions are:

1. A Radio Frequency Spectrum Analyzer with a Z Axis input.

2. A Video Waveform Monitor with field and line select capabilities and the output of horizontal strobe or the CRT brightening pulse.

3. Time Selective Spectrum Analysis (T.S.S.A.) is accomplished with Z Axis Control Module to condition and control the timing pulses from the Video Waveform Monitor to the Z Axis input of the Spectrum Analyzer.

4. A television demodulator with a base band video output.

5. A means of storing the observed presentation of the Spectrum Analyzer, such as a storage scope and polaroid camera.

EQUIPMENT CONFIGURATION

1. The equipment is connected as shown in the functional diagram, using proper techniques in handling radio frequency and video signals with coaxial cables.

2. The input level of radio frequency carrier of television signals should be of sufficient level to display at least 60 dB of dynamic range of signals above the noise floor of the spectrum analyzer.

3. The Spectrum Analyzer is to be set to scan radio frequency spectrum of interest with the demodulator tuned to the TV Channel which occupies the same frequency.

4. The Video Waveform Monitor line select will display an appropriate line, with the sync select on external, the input select on A-B. (With the input select on B, the Z axis timing pulse is presented)

5. The Z Axis Control Module controls the time delay and duration that the Spectrum Analyzer's Z Axis is turned on. The Z Axis module is triggered by the strobe output of the Video Waveform Monitor.

6. The Spectrum Analyzer is set to scan the frequency range at a rate of from 5 to 25 second per horizontal centimeter, the single scan mode is manually started, the vertical gain is set in the usual manner. The IF bandwidth would use 300,

100 or 30 Kilohertz depending on the desired information.

When all equipment is connected and operating properly, the Spectrum Analyzer CRT is turned off except for the very short duration in time selected by the Video Waveform Monitor and the Z Axis Control Module. The configuration allows repetition of samples of the same duration and time during a television frame, the duration can be from 4 to 65 microseconds at a rate of 30 times a second. The Spectrum Analyzer scans the spectrum that contains the video modulated RF carrier and associated side-band information that the demodulator is tuned to, such as 52 to 62 megahertz for the Spectrum Analyzer and Channel 2 for the demodulator. The short duration that the CRT is turned on is then stored in progression of the scan of the Spectrum Analyzer displaying the amplitude of the R.F. energy that is detected during these short duration that the Z Axis is turned on. The number of samples is dictated by the speed of the horizontal scan of the Spectrum Analyzer and the desired resolution of the recorded data.

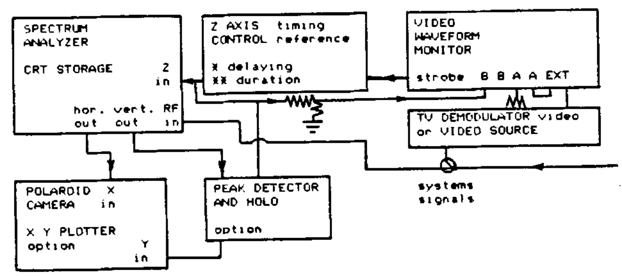
The Video Waveform Monitor is multi-functional. Initially selecting the line in the video frame that is to be analyzed, the horizontal strobe is sent to the Z Axis Control Module. Also displayed with that line is the desired delaying time with the Spectrum Analyzer Z Axis duration time by displacing the normal presentation on the Video Waveform Monitor. The presentation allows critical adjustments to be made on the delaying and duration controls. A small time differential occurs due to the delay in propagation of the R.F. signal through the Spectrum Analyzer of 1 to 3 microseconds depending on the I.F. bandwidth.

The time is rare that you could observe a Cable System when there is no video information being transmitted so that spurious signals can be easily observed with the normal Spectrum Analyzer Techniques. The video signal is made up in such a way that there are times when there is no change in transmitted carrier power and, therefore, no transmitted side-band energy. It is during these short intervals of time that observation of the television channel can be made without the presence of sideband R.F. energy. A blank line during the vertical interval is such a time. 50 millionths of a second is a long enough time when using the technique described here.

The I.F. bandwidth setting of the Spectrum Analyzer will determine the resolution desired, 30 Kilohertz for observing spurious C.W. signals whereas noise level measurements can best be made using a 300 Kilohertz I.F. bandwidth.

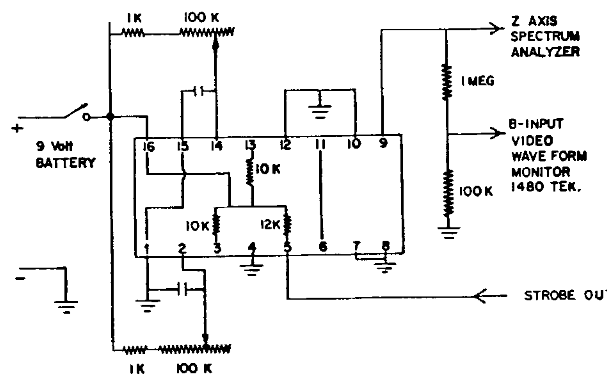
Most observations will be made with the Spectrum Analyzer in the 10 dB log vertical display. The resolution is better than 1 dB. Where comparison of amplitude is a narrow range, such as with the vertical Interval Test Signals Multiburst, then 1 or 2 dB per vertical division provides greater amplitude resolution.

The polaroid photographs are of Spectrum Analyzer stored CRT and the Video Waveform Monitor CRT displays. The plots are from the vertical output of a Spectrum Analyzer and time domain vertical interval test signals are from a Video Test Signal Generator with associated timing delay and duration pulse from the Z Axis Control Module.



FUNCTIONAL DIAGRAM

TIME SLECTIVE SPECTRUM ANALYSIS



Z Axis Control

C-MOS ics
C4051P HEP
CD4098BE RCA
ECG 4098B SYL

ILLUSTRATIONS

Graphic plots are used here as they best illustrate the magnitude of the information that can be observed and recorded.

The plots showing Channels 2 through 5 are as performed on an operating system.

The entire vertical interval is displayed with markers defining the start and stop of the selected portion to be analyzed. The next time domain display is of a single horizontal line which is included in the portion of the vertical interval display. The third time domain display indicates the time and duration of the Z Axis Pulse that is sent to the Spectrum Analyzer and to the B input of the Video Waveform Monitor.

The graphic plot is a reduced copy of a standard size graphed plot of a Time Selective Spectrum Analysis with a greater than 70 decibel display of video carriers showing Channels 2 through 5 with the associated audio carriers.

The polaroid photos are of stored displays on a Spectrum Analyzer, the R.F. energy of a single picture carrier and sideband energy from one equalizing pulse and of a VITS multiburst.

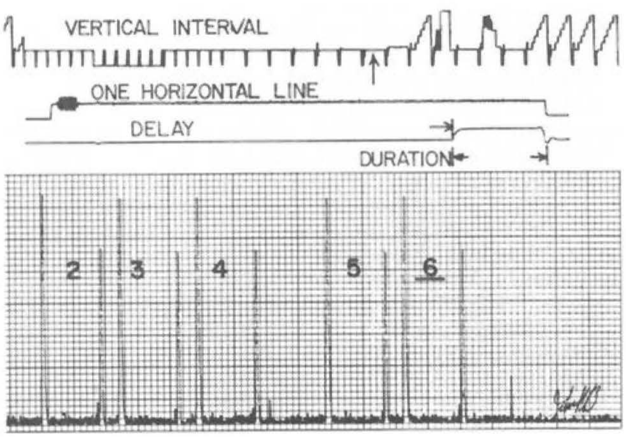
SPURIOUS SIGNALS

The plot is of a single television channel with amplitude modulated visual carrier and audio carrier.

The I.F. Bandwidth of the Spectrum Analyzer is 30 Kilohertz. The vertical calibration is 10 dB per major division and scan is 2.5 megahertz per major division.

The single spurious response is residual color subcarrier from a Tektronix 147 Video Signal Generator, and greater than -70 dB from picture carrier level.

The duration of the Z Axis is approximately 5 microseconds. The delay allows the narrow band I.F. to respond properly.



SPURIOUS SIGNALS - 30 Kilohertz I.F. Bandwidth 10 dB log the same time is selected for noise.

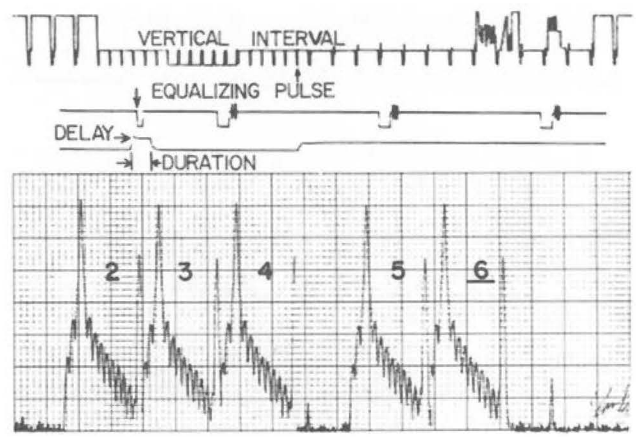
The carrier level with the blank line is 2.5 dB below peak carrier level at the sync tip.

PICTURE QUALITY

The most significant observation that can be made of a television channel is to examine the energy distribution in the side band frequencies of a square wave pulse. The best equalizing pulse for observation is at the start of line 9 of field 2.

The Spectrum Analyzer I.F. band is set to 100 Kilohertz. Although 30 Kilohertz will also perform, it is too detailed for general use.

The number of responses on the upper sideband on a scale of one to ten rating of picture quality is easy. The noise and frequency response contribute directly to the quality of the picture and the rating. A normal horizontal sync pulse will also respond but will normally contain the color burst and have more responses.



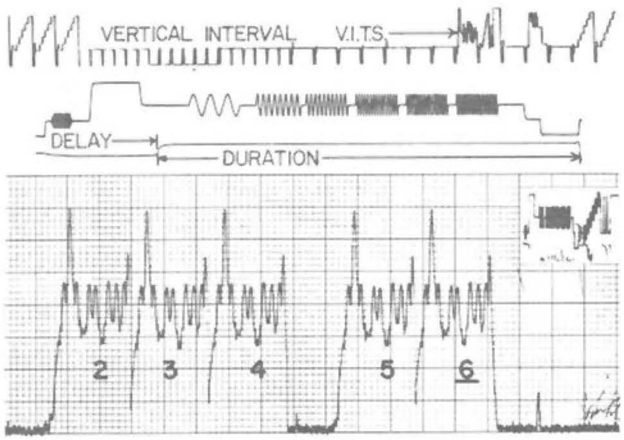
PICTURE QUALITY - 100 Kilohertz I.F. Bandwidth 10 dB log.

AMPLITUDE FREQUENCY RESPONSE

To prove that the processors at the headend are up to FCC standards or want to determine the effect that multipath propagation has had on the off-air television signals, T.S.S.A. will provide amplitude response by analyzing the Multiburst of the Vertical Interval Test Signals.

The Z Axis duration in excess of 63 microseconds will include a horizontal sync pulse which will give you peak carrier level. Confining the duration to include only the multibursts, will lower the carrier level so that 300 Kilohertz I.F. will show the response of the upper and lower side band energy of the .5 megahertz burst. Dual displays with 300 and 100 Kilohertz of I.F. bandwith will indicate relative duration of each burst of the multiburst.

The vertical display of 1 or 2 dB per one cm. division will make accurate amplitude measurements to the degree of compliance to channel R.F. amplitude response standards. 10 dB per vertical division would show peak picture carrier and adjacent out of band response.



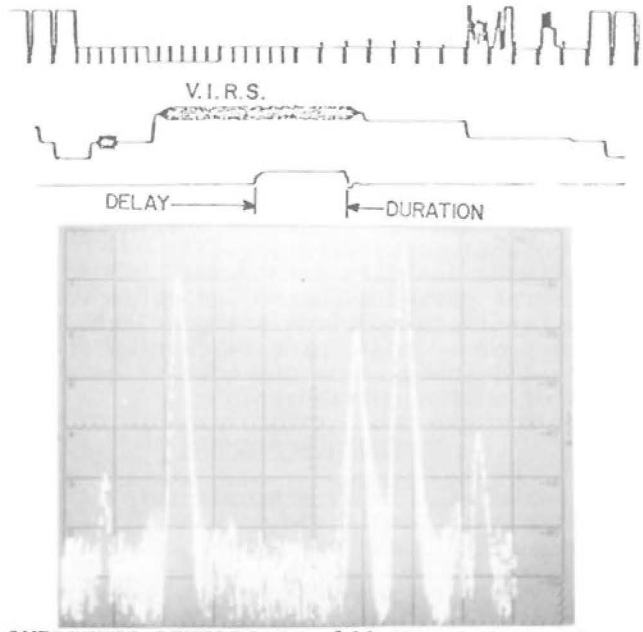
R.F. AMPLITUDE RESPONSE - 300 Kilohertz IF Bandwidth 10 dB log.

AMPLIFIER LINEARITY

The relationship of carriers within a television channel that can interact from nonlinear amplification can be shown graphically with T.S.S.A.

Most television stations transmit a Vertical Interval Reference Signal so that the color of the video signal can be referenced. A short duration of the transmitted color frequency can be selected and the linearity of an amplifier or processor can be determined from the component of the audio carrier and color signal that are mixed with video carrier and be detected 920 Kilohertz from the picture carrier. Using 100 Kilohertz I.F. and a selected time during the V.I.R.S., the mixing of the audio carrier and the color signal will show as a 920 Kilohertz signal near the picture carrier. The 920 Kilohertz beat will prove the linearity of the amplifier or processor under test.

The Spectrum Analyzer is set at 100 Kilohertz I.F. and the Z Axis duration of 5 microseconds near the termination of the color reference. The step up in the video carrier level immediately after the V.I.R.S. should be avoided as the energy level change will produce sidebands that will obscure the desired observation with plotting techniques.



AMPLIFIER LINEARITY - 100 KHz I.F. Bandwidth, 10 dB log vertical.

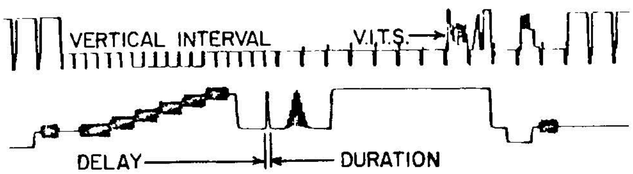
EXERCISING 2T RESPONSE

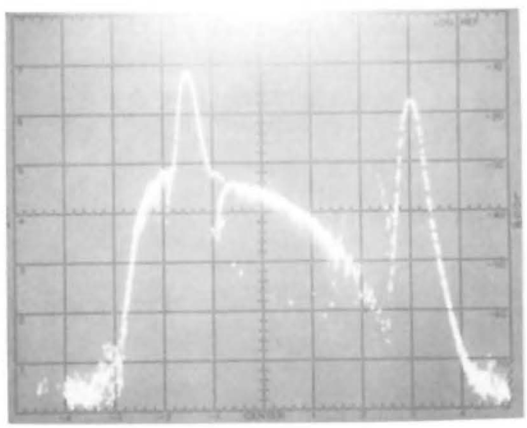
The 2T pulse of the V.I.T.S. has the shortest duration, is close to other video test signals and is the hardest to capture.

There are some uses for this display when used to determine distortion of envelope detectors of demodulators and are similar to analysis of leading or trailing edge of the bar signal which has a shorter H.A.D. The accomplishment of this measurement will be the ultimate of accuracy that the two control of the Z Axis Module can accomplish.

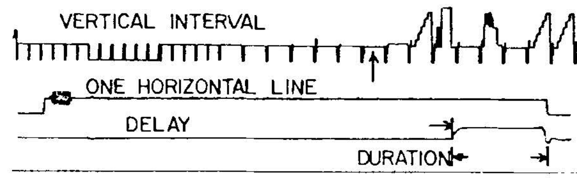
The Spectrum Analyzer will only perform with 300 Kilohertz or wider I.F. band width. The duration of the Z Axis pulse will have to be observed closely on the A-B presentation of the Video Waveform Monitor because of the difference in propagation of the R.F. signal through the Spectrum Analyzer. The duration will appear to occur during the 12.5 T pulse due to the difference of propagation. There are color frequency test signals before and after the 2T pulse which could interfere if the delay and the duration are not properly set.

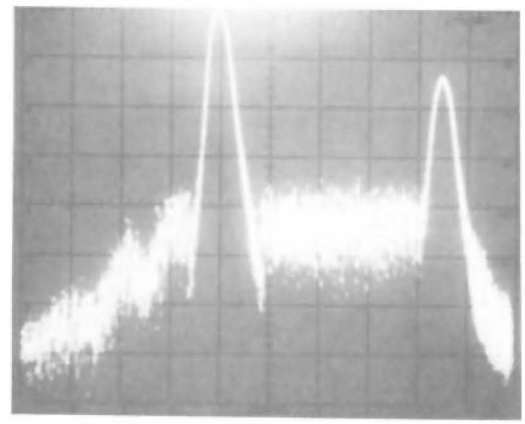
Phase canceling of the picture carrier to blanking level will allow presentation of only the sideband energy. The carrier canceling technique can be applied to any of the T.S.S.A. procedures.





2T RESPONSE - 300 KHz I.F. Bandwidth, 10 dB log vertical.





CARRIER TO NOISE - 300 KHz I.F. Bandwidth, 10 dB log.

NOISE MEASUREMENT

Although the noise of a television channel can be measured with a 30 Kilohertz bandwidth I.F., 300 Kilohertz will measure the noise with greater resolution. Calibration can be achieved directly with this noise plot where the noise was introduced at different levels with -20, -40 and -50 dB below peak video output from the Tektronix 147 Video Signal Generator.

Normal propagation and processing will present very little difference in noise energy distribution. Poor signal processor alignment can be seen as well as the signature of a dual channel video recoder or a satellite earth station receiver.

When the Video Waveform Monitor is on manual line select and placed on line 4 in the vertical sync pulse time, true peak video carrier can be recorded. Care must be exercised on these lines as incorrect timing will allow energy from nearby sync pulse to be recorded.

NOTES

The C-MOS integrated circuit may require different approaches in the disposition of the unused pins. The configuration in this circuit has worked for most C-MOS ICs. Some ICs will work if the unused pins are left to float but can cause unexpected results.

OTHER APPLICATIONS

Using the pulse from the Z Axis control unit and applying this pulse to control the output of a tracking signal generator, high level sweep of all the headend equipment can be made without interference to normal operation of a cable system. The applying of sweep signal during a blank line in the vertical interval makes this type of sweeping possible. Offset frequency can produce video sweep at base band to test modulator at their output frequency.

T.S.S.A. of TV signals on FM carriers can be as revealing as T.S.S.A. at base band frequencies. Microwave AM and FM signals can also be measured for many of their characteristics.

SUMMARY

The Time Selective Spectrum Analysis, by using the Z Axis control module in conjunction with the Video Waveform Monitor and Spectrum Analyzer, will allow considerable additional utility to the Spectrum Analyzer. Additional understanding will occur concerning the theory and operation of the modulation characteristics of Radio Frequency Carriers.

There are many uses suggested in this paper which describes the minimum equipment that may be found in a Cable System. With other equipment, such as a plotter, tracking generator, offset frequency generation, the utility will be even more greatly expanded.

REFERENCES

1) John L. Huff, "System Performance Using Time and Frequency", Communications/ Engineering Digest, Nov. 1976.

2) John L. Huff, "Time and Frequency Measurements: Part II", Communications/ Engineering Digest, Mar. 1977.

3) R. H. Vivian, "Some Methods of Automatic Analysis of Television Test Signals", Journal of the SMPTE, Dec. 1971.

4) Clifford Schrock, "Sideband Analysis for TV", Tektronix Application Note AX2933-1.

5) G.A. McKenzie, "Automated Television Waveform Measurements by Use of a Digital Computer", Journal of the SMPTE, Sept. 1974.

6) Hewlett Packard "Spectrum Analysis... Pulsed RF" Application Note 150-2, Nov. 1971

TIME TELETEXT - PRESENT AND FUTURE

Pedro Barros, Senior Consultant, Barros & Associates Ltd.
John Lopinto, V.P. Technology, Time Video Information Services Inc.

ABSTRACT

Time selected full channel over VBI teletext on the basis of technical and business considerations. Full channel provides the tools for a very extensive service, and the support for insertion at the local level without interference with the national component of the service. Content is managed by the editorial staff, using the concept of magazine as a logical group of related material. Access times are adjustable separately for each magazine.

The editorial tools provide for effective integration of written material and graphics, with automated input sources and a computer archive of reference material.

Telesoftware is used as an integral part of the editorial content, and designed to promote system interactivity with the user. Time's leading role includes the development of new encoding techniques for telesoftware and microprocessor operating environment.

Insertion into the video signal is provided by a specially designed inserter, based on dual microprocessors, under control of the master editorial host computer. Transmission to the local markets is achieved via satellite and full video NABTS. Current design of cable networks is adequate for teletext distribution provided proper maintenance is maintained.

A low cost decoder is being developed, which will support both VBI and full channel, and in addition will be capable of running telesoftware. Ultimately, the acceptable configuration of teletext will be determined by the consumer's perception of value, and the economics of the CATV industry.

INTRODUCTION

Two and a half years ago, the Video Group of Time Inc. set out to develop a teletext service so compelling and encompassing that it could stand alone as a major business activity for the Video Group. Until that time, teletext activities were focused on using about 1% of a television signal known as the vertical blanking interval, or VBI. We decided that, by using the entire television signal to carry teletext data, a total content in the order of 5000 screens instead of 100 could form the basis of a comprehensive service.

But quantity wasn't enough. It was clear that content would be the characteristic that would give the service its appeal. Technology, on the other hand, would be the foundation upon which innovation and versatility would be built. To this end, we initiated several technical projects designed to give our editorial staff the maximum flexibility in designing the service, and to simplify the technical process necessary to construct the business.

FULL CHANNEL TELETEXT

The Potential of Full Channel

In May, 1981, Time and Norpak of Ontario, Canada, began to develop the first full channel encoder for the NABTS (North American Broadcast Teletext Specification) teletext standard. The encoder had to accept teletext screens from a Host computer, store them, identify them for broadcast, organize them into logical groups of content called MAGAZINES, synchronize them for transmission with a video signal, and insert the data onto the video at a rate of over 5 million bits a second. In addition, a proprietary technique was developed to allow the insertion into our national feed, of teletext screens generated in local markets by, say, a newspaper. Such insertion should be possible without the need for complex computers, and without compromising the integrity of the national feed.

But full channel teletext had to somehow be more than just 50 times more content than VBI teletext. We set out to balance breadth of content with depth of content. Also, we cut the cycle time in half from 20 seconds, which is typical of VBI teletext services, to 10 seconds for the Time teletext service. An additional characteristic of the Time service is the ability to create different cycle times for different magazines on the service. As an example, the News section might have a worst case access time of 3 seconds while the Weather pages might be accessed in 10 seconds at worst. We have the ability to balance access time, magazine size and the overall size and content of the service.

All of this versatility, however, must be managed. The teletext screens are identified during transmission as PAGES, each with a unique number and placed into a MAGAZINE by an editor, with the magazine being identified by a number. Technically, this process is very straight forward, but from the point of view of the user at home it could have been a clumsy and confusing task to navigate the full channel teletext service. Our Editorial team developed a technique of on-screen REFERING to allow the user a simple, logical method for traversing the thousands of pages available on the service (Figure 1).

In addition, the local content produced by The Copley Press in San Diego and the Orlando Sentinel in Orlando, our test markets, use the same software to present both a technically and editorially integrated service to the user at home. Finally, we have developed a method to allow, in the future, the ability to tier or package different groups of magazines should market conditions warrant.

The Full Channel Inserter

The basic difference between full channel insertion and VBI stems from the very short time available in full channel to manage the insertion process.

The insertion process itself is handled by a dedicated microprocessor, which reads data directly from RAM. System housekeeping and administration is performed by a separate "master" microprocessor, which is responsible for the interfacing with the editorial Host, and for managing the disk resident database (Figure 2).

Again, Time is looking at alternative distribution techniques, and ways of taking advantage of other existing or developing technologies which may be in the interest of the marketplace or of the cable systems.

TELESOFTWARE

The inclusion of telesoftware in Time's service is to be taken in a different light from what has been done by other organizations. The emphasis is not in the software itself, but rather in a totally integrated service. The goal is not to distribute software to run in general purpose computing machines, but rather to enhance the capabilities of the user terminal in the home.

In other words, telesoftware is a tool rather than an end in itself. Its use greatly increases the degree of interactivity possible between the user and the service. It brings to the home some of the power otherwise available only to "two-way" systems, without the need for expensive two-way plant or expensive remote computing hosts serving a multitude of users.

Examples of what is currently being offered by Time's teletext include, amongst others:

- Interactive computer games with full graphic capability using the PLPS standard, as well as locally generated sound (PLPS is the North American Presentation Level Protocol Standard);
- Automatic computation of a user-definable portfolio of stocks and/or commodities (the user specifies his own interests, the terminal "remembers" and captures only the items of interest);
- Local generation of user dependent data and graphs, upon request (e.g. biorythms).

The possibilities are limitless, and Time is and will be experimenting with a variety of offerings.

The currently implemented software is (for the time being) heavily dependent upon the microprocessor used on the home decoder (Intel 8088). In order to achieve processor independence, Time has developed an encoding technique based on the PLPS proposed use of G-sets. It is expected that such work will lead to a universally acceptable encoding technique with all the corresponding benefits of program transportability and decoder-independence of a teletext service.

The current telesoftware development environment (for the production of an integrated editorial product) includes (Figure 3):

- A number of microprocessor based software development stations (IBM PC);
- Facilities for the more "conventional" creation of ancillary PLPS graphics pages (Norpak IPS-2);
- A full channel inserter, which generates the same video signal to be expected in the field (Norpak TES 2);

- A home user decoder, running the same TVIS operating system as the target decoders. (Developed in co-operation by Time, Norpak, Zenith, and Owl.)

This environment has proven very satisfactory for the development of editorial telesoftware, and in general, very little on-line debugging has been required. On-line debugging tools, such as Intel MDS, have been used extensively to help develop the operating system.

THE TELETEXT NETWORK

The Editorial Center

The central piece of hardware is a DEC-VAX computer, running editorial software provided by Infomart of Toronto. Writers compose their stories directly at their VT100 terminal; in the process, they have access to wire services input directly into the host computer, and to a "morgue" library of archival material (Figure 4). Any required graphics will be prepared using special "Page Creation Terminals", supplied by Norpak (alternative graphic stations, developed by AT&T and by Cableshare, are currently under evaluation).

The development of telesoftware is considered part of the editorial operation, as described before. The output of the process is channelled through the Host, before being output into the system.

Automatic capture of wires is not limited to news for further editorial work: it also includes Sports, Weather and TV data information of relevance to the local markets addressed by Time's teletext service, as well as financial information. The latter is supplied in a pre-processed form which allows for smooth integration with Time-developed telesoftware running in the home decoders.

The VAX Host controls the video insertion process occurring in the Full Channel Inserter through an error-protected RS232 serial link. Due to networking requirements, some of the information to be transmitted is separately fed into a VITL encoder supplied by Video Data Systems.

The inserter is fed by a conventional video source, and the signal is cascaded through the VITL encoder.

Transmission

The output of the inserter/encoder combination is fed to the uplink to SATCOM-F4, and received at the local market ground station, operated by the local cable partner (Figure 5).

Baseband video is fed into the local inserter, which is under control of the local Host. This is operated by the newspaper partner, who is responsible for local content and features.

The editorial tools and operation of the local newspaper are similar to the national ones, with the exception of telesoftware development, which is limited to Time's national centre, at least for the time being.

It should be stressed that the current setup was designed with expediency in mind, the goal being the early availability of the tools for market testing of Time's concepts, and its refinement where necessary. Time is constantly reviewing the technological tools to be used in the near and far future, with the basic idea of reducing capital costs and operational expenses.

Cable Plant

Time's teletext is using previously existing plant, some of which is of rather old construction. The fears voiced by some people as to whether it would be feasible to transmit data at the 5.72 MHz rate have been proven unfounded by Time's experience so far.

Nothing inherent to the current design of cable networks precludes their use for the transmission of NABTS teletext. However, it should be strongly emphasized that proper maintenance of the system is essential in order to keep error rates within the limits of what is acceptable to the paying subscriber.

Time is carrying further investigations into the optimization of certain components, such as head-end modulators, for the specific purpose of passing teletext signals (as opposed to conventional video).

THE FUTURE TERMINAL

In December of 1982, Time announced a major co-development effort with Matsushita Electric Industrial of Osaka, Japan, to produce a reliable, low-cost teletext terminal for the CATV market. The terminal will meet all fundamental specifications of NABTS and will be available in three different forms to meet various interface situations in the CATV home. The terminal will not only decode Time's full channel teletext service but will also decode broadcast originated NABTS VBI teletext services.

Time and Matsushita are adding a few innovations to this product. First, we have developed a protocol for the transmission of telesoftware in a defined, terminal independent manner that will work in concert with the NABTS standard to expand the nature of the service far beyond static screens of information. Second, our method of tiering the teletext service will be supported by the terminal.

Perhaps the most interesting aspect of the terminal is its expandability. The terminal allows for the optional addition of more memory for telesoftware, joysticks and interfaces to other devices such as printers, modems and other computers in the home.

But, as in any consumer product, the allowable cost and its associated performance will be determined by the marketplace. For it will be the consumer's perception of value of teletext and the economics of the CATV industry which will need to be understood to optimize the service. Time is undergoing this process right now, and at the same time we are also planning for the future.

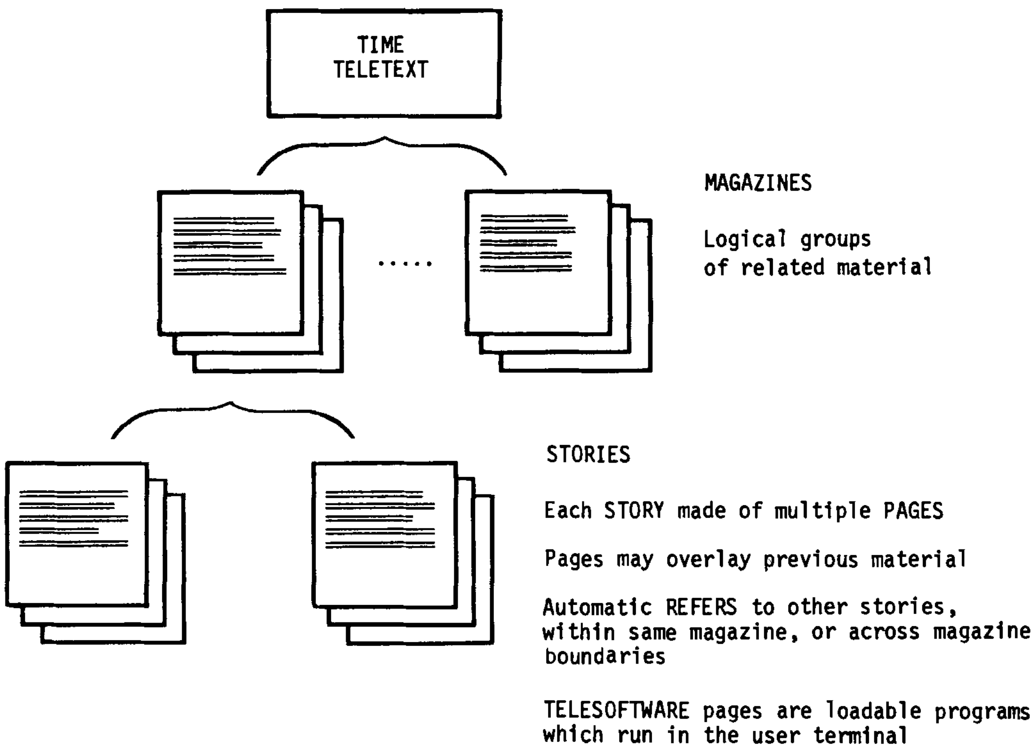


FIGURE 1 - TIME TELETEXT CONTENT STRUCTURE

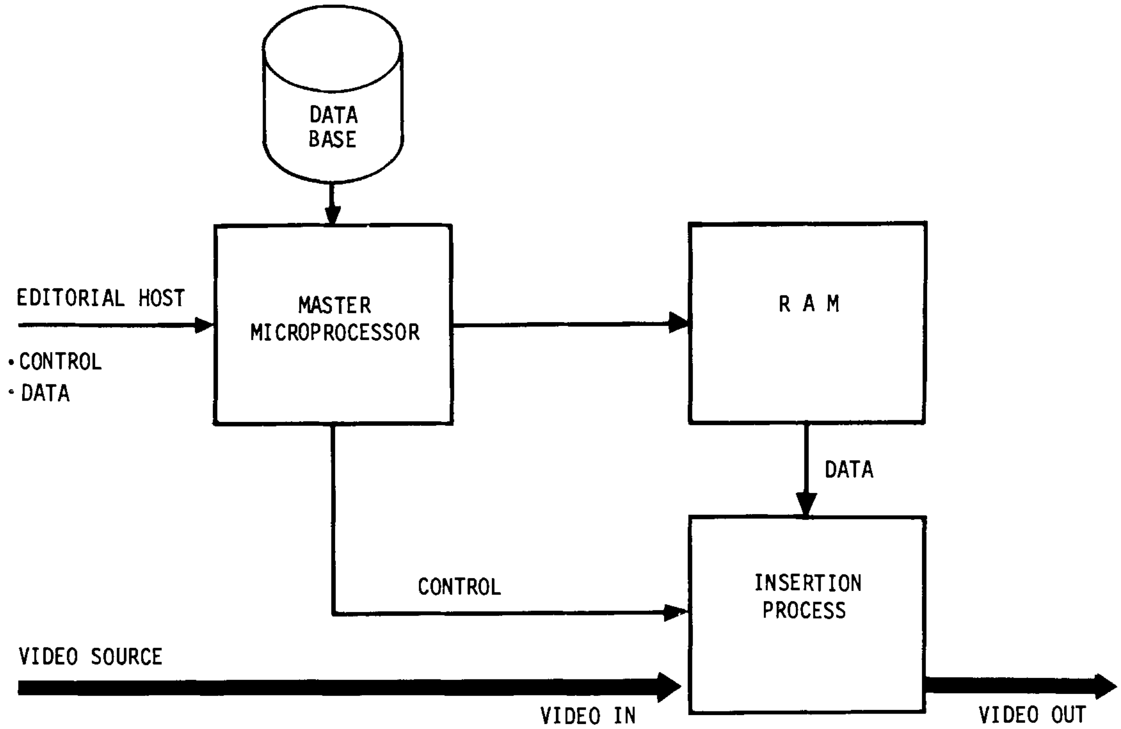


FIGURE 2 - FULL CHANNEL INSERTER

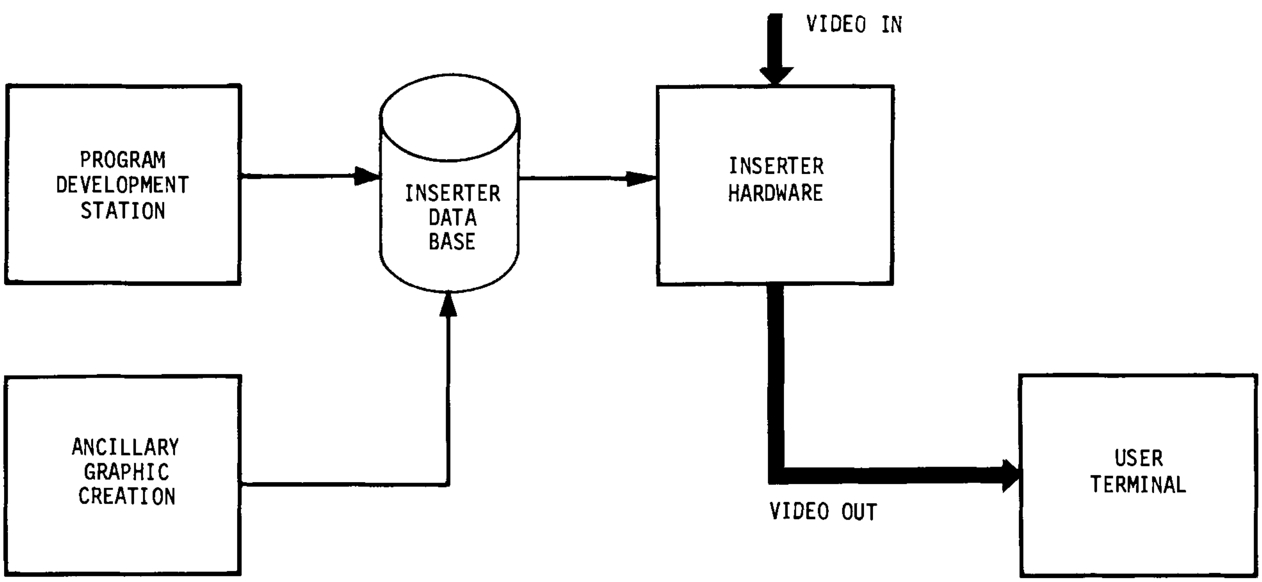


FIGURE 3 - TELESOFTWARE DEVELOPMENT ENVIRONMENT

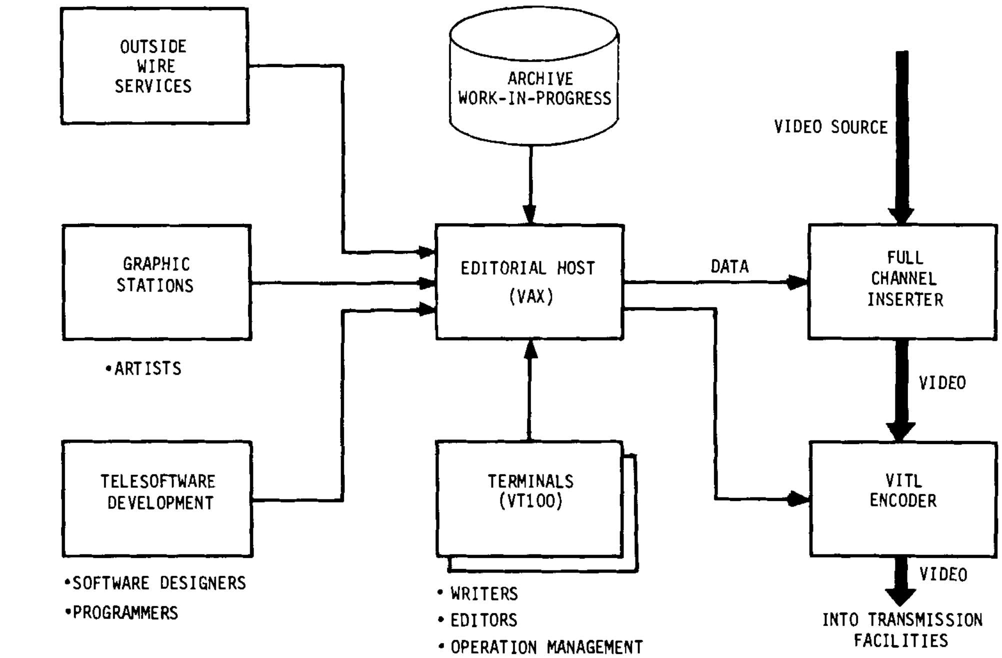


FIGURE 4 - EDITORIAL CENTRE

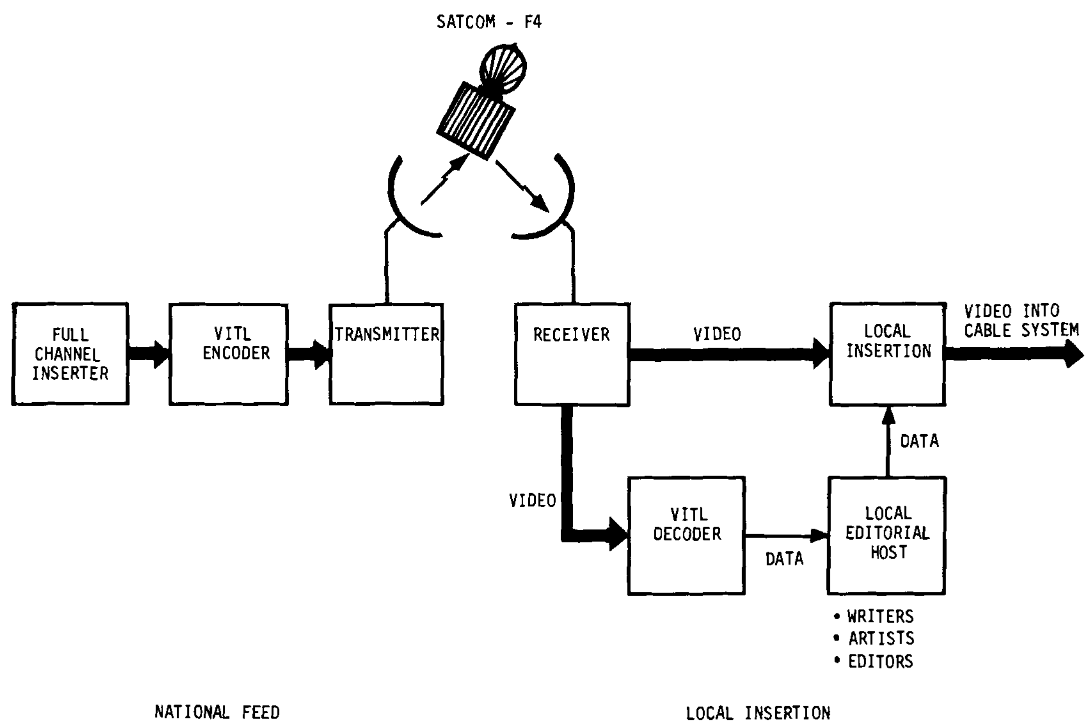


FIGURE 5 - TELETEXT TRANSMISSION

VIDACOM™ SYSTEM FIELD TRIAL OBJECTIVES AND RESULTS

Michel Dufresne

VIDEOTRON COMMUNICATIONS LTEE

The VIDACOM™ system developed by Vidéotron Communications Ltée has been introduced in early 1983 as a field trial in selected areas of the Vidéotron cable network in Montreal. This system presently supports 375,000 subscribers. This paper summarizes the major objectives of this field trial as derived from the test plan. Three major aspects are the subject of particular attention in the context of the field trial: Technology, services and network architecture.

Firstly, the field trial includes a large scale verification of the technology used in the VIDACOM™ system, although all new technologies were already tested through laboratory prototypes. The system is based on OSI packet data transmission at high speed of 4MB/sec. within a frequency bandwith of 6MHz (equivalent to a TV channel). The system achieves high quality transmission with 10^{-8} bit error rate or better. The protocol used permits both selective and interactive services.

Secondly, the field trial is used to collect precious actual information about the subscriber's behaviour with respect to new services; (text, video games, home computer, pay TV, addressability, captioning, hybrid video/data).

Thirdly, the field trial is the first "test bed" for the network architecture, based on the "open system" concept whereby the external world of information and service providers and user's peripherals equipment can be connected to the VIDACOM™ system using standard telecommunications protocols.

I. BACKGROUND

Vidéotron Group is one of the tenth largest MSO in North America with a total base of more than 650,000 subscribers geographically distributed across the province of Québec, CANADA. Four PTV services are being offered since February 1st, 1983 with a penetration rate rapidly approaching 10%. Since 1975, Vidéotron has been offering a group of various type of services such as:

- TV on request (arts, sports, children, etc.)
- France's programming channel
- Videogames
- Video classified ads
- Telidon information channel
- Specialized TV channels (consumer, ethnic)

With the arrival and definition of new services, Vidéotron has established a research and development program to develop an integrated data communication system named VIDACOM™ . One of the main objectives of such a development was to define a system that will eliminate the use of parallel and non-compatible approach now used for each different service. The use of a unique protocol will reduce the total cost of offering these services, will reduce the complexity of utilisation by the user and will rationally use the bandwith capacity of CATV networks.

II. INTRODUCTION

The system is based on a broadband digital communications approach with 1-way and 2-way capabilities in a sub-split subscriber area network or entertainment CATV network. The VIDACOM™ system is designed around data processing concepts as used in packet transmission system and is structured based on the OSI model of ISO. (International Standard Organization).

Its design makes VIDACOM™ fully transparent to the network architecture (star, tree, loop, bus) in addition of being transparent to the medium itself (satellite, microwaves, coaxial cable and eventually fiber optics). The broad definition of its communication protocol structure offers the capabilities of supporting a diversity of services such as Video control and addressability, Information services based on selective and interactive videotex and transactions, Data transmission such as software downloading of home computers software, and finally Audio options such as stereo or bilingual multisound features.

Special other services are also provided by VIDACOM™ using multiple types of signals and their integration to produce specialized services such as captioning, user's guide, video/data programs, user's programming options and many others.

This paper will cover the description of a field trial being conducted in Montreal based on 450 interface units. A summary of the objectives and results of the experiment will be presented for the following aspects:

- The technology used:
  OSI protocol, packet transmission, packet

format, energy spectrum, performances (BER), selective-interactive services, signal transparency, full addressability.

- The network architecture: no needs of networks modifications, selection of any 6 MHz bandwith for data channel, AML compatibility, one-way and two-way capabilities and compatibility, IP and user gateways.
- The services: Tiering with 256 classes, multi-magazines of information-database, response time, user's guide and content's guide, high security PTV based on public key, reprogrammable keypad (converter, information and games), captioning and data overlay services, software downloading for personal computer and video games.

Results will be presented on each of these subjects in relation with the field trial objectives that were addressing the following elements.

- technology
- user/system interrelation
- service market studies/research

III. TECHNOLOGY DEFINITION

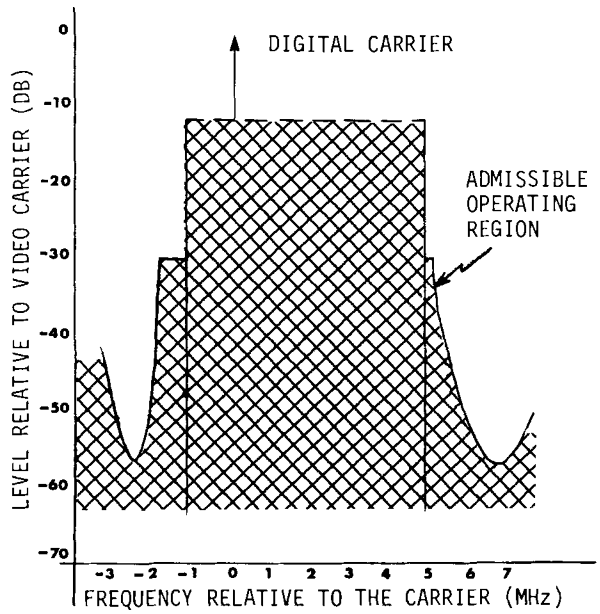
The technical objectives were to demonstrate the feasability and reliability of high speed data transmission on a subscriber's cable network concurrently with the offering of standard television services.

The definition of digital receiver, of low cost, handling high data rate transmission of more than 4Mb/sec. and providing performances of bit error rate of less than 10^{-8} was the main initial concern. In addition it was necessary to demonstrate that such a signal can be transmitted via any 6MHz TV channel without interference with other adjacent television channels (triple beats, sound buzz etc.). All these demonstration and tests were conducted with satisfactory results approved by DOC even when using a data carrier level equivalent to adjacent video channel carriers.

Figure III-A shows a template of energy level measured in a 6MHz video channel. The digital signal, for different transmission sequences met this maximum energy level. Many tests, both suggestive and technical, were made with the conclusions that no impacts or interferences are created by the data channel defined.

FIG.: III.A

TEMPLATE SHOWING LEVEL CONSTRAINTS FOR A DIGITAL DATA CHANNEL



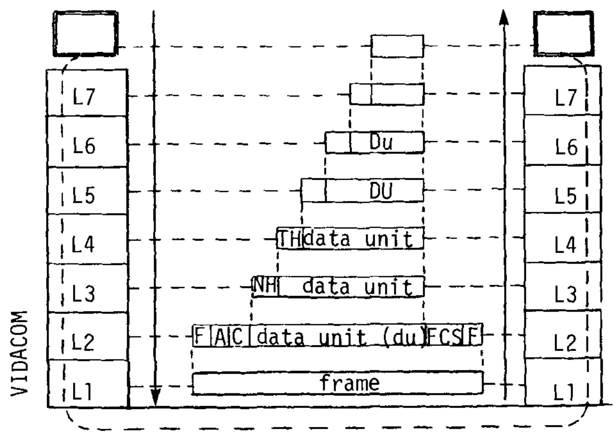
Packet transmission is used worldwide in data network of X25 type in telephone network environment. The implementation of a packet transmission system working in both one-way and two-way modes on a broadband and long distance CATV network is particularly new, specially in residential area network. The objectives of high speed of transmission, low cost of user interface and currently used CATV network architecture did define specific design requirements applicable to hardware components and communication protocols.

The choice of the structure of the communication protocol, namely OSI model of ISO, was made considering its applicability to the diversity of services to be supported. The first three layers of the OSI protocol were defined for VIDACOM™ leaving other levels for future definition depending of the type of services to be supported.

Figure III.B shows the standard levels of the OSI model. Of particular interest, the logical level (2) is also defined in Figure III.B. This format is used for all data services handled by VIDACOM™.

FIG.: III.B

OSI PROTOCOL LEVELS



COMMUNICATIONS PATH
(PHYSICAL TRANSMISSION MEDIA)

Legend:

L1:	PHYSICAL	L5:	SESSION
L2:	DATA LINK	L6:	PRESENTATION
L3:	NETWORK	L7:	APPLICATION
L4:	TRANSPORT		

The addressability features of VIDACOM™ offers the capacity to direct any packet of variable size (0-2K bytes) or multiple packets to any specific user linked to the network. These packets are service's format transparent which mean that the coding structure of the information contained in every packet may be different from one to the other. That feature defines the capabilities of PTV addressability, of videotex pages transmission (ASCII, MOSAIC, GEOMETRIC) of any format, of binary software transmission (home computers) and more as required by the end-user application.

The system's communication protocol concurrently supports one-way and/or two-way transmission. This feature permits, in a one-way mode, to broadcast a sequence of packet containing various types of services on the network. The user may be authorized to select some of the services if he has previously been addressed for the proper tiers. This system, based on a capacity of 1,000 packets/sec. is equivalent, at the user level, of having access in an interactive fashion to a data base of nearly 20,000 pages (information, software, etc...). This mode is often called one-way interactive because the user has the impression of interacting with a computer data-base. An important result is the fact that no matter the number of users interacting with this data base, the average response time is constant.

In the two-way mode, the user may inquire for information not available in the one-way mode or send transactions for remote processing. The system is built to support up to 10,000 users active on any one trunk of a head-end system. This limit is well over the capacity of any host processor known today. Interconnections to multiple remote data bases or processing centers are provided through head end gateways systems.

IV. NETWORK ARCHITECTURE

Considering the present technologies of network design and the investment done by cable operator, one main concern in defining VIDACOM™ was to define a data communication system that can be implemented in standard networks of various capacity such as 12, 20, 35 or 50 and over channels capacity. It should not be necessary to change the architecture of the network because of the introduction of new services. In addition, it should not be necessary to install a large amount of new hardware in the network except bidirectional transmission modules.

When designing VIDACOM™ , it has been concluded that many new services can be offered with a one-way system which should smoothly be able to evoluate to full two-way capabilities when and where required.

Because of its end to end design approach (head-end to subscriber), the system does not require large investment in network upgrading or modernizing. A head-end system is installed with one-way or two-way user's interfaces that can concurrently exist in the same network.

For evolution, compatibility and modularity, a 6MHz bandwith is used for downstream while two 1 MHz bandwith are used upstream. The downstream bandwith, equivalent to a TV channel, may use any of the channel available in the spectrum of the cable network. The system can also work in dual cable or mid-split system.

Full compatibility with AML (low-high power) is achieved by the signal formatting and modulation used. This permits to serve many remote sub-head-end system from a central or regional head-end. At both, the head-end communication center of VIDACOM™ and at the subscriber's interface level, gateways or ports are available to interconnect with remote service's center or to attach peripherals units to the interface such as a home computer.

An important feature is the capacity to evoluate from a one-way system to a two-way system when the CATV network is upgraded to more channels and two-way transmission. This offers to any present network the capacity to start offering new services and increase these services when necessary without obseleting equipment already installed.

V. SERVICES

All services offered via the system are managed or controlled by tiering of services using up to

256 different tiers per subscriber. These tiers can be remotely changed by direct addressability of each unit at a rate of 10,000 subscribers / sec.

These tiers cover video, audio, information or data services which permit to any user to subscribe to a different mix of services. The security of addressability and tiering is achieved by using the high speed data channel which is encrypted at communication level. Complexity of utilisation of services is minimized by providing to each user simple procedure to get access to preferred services or services available.

The system uses a built-in user's manual that the user can easily access by entering "?". This action will give him access to a specific chapter of the user's guide related to what the user was doing or trying to do when he hit the question mark. After reading the necessary information, the user may resume its operation at the point he left when he asked to access to the user's guide.

This feature offers an up to date documentation of the "how's" and what's" describing the functions and the services supported by the system. This user friendly approach is equivalent to a self educating process of how to use the system.

The information requested is displayed on the screen in full page format based on a subset of TELIDON (NAPLPS) supporting ASCII, MOSAICS, DRCS and graphics capabilities or in an overlay mode with the TV picture. In the field trial a full PLPS decoder is provided in addition to a mini-TELIDON decoder with enhenced features such as overlay and animation. Final decision of features of displays will be determined taking into account the various information services and the user's feed back gathered during the field trial.

Special services such as multi-language captioning is supported by the system permitting to display NCI or CCDA captioning format. (Associations).

In the selective mode (1-way), the users have access to a data base of information and softwares structured in a CODASYL like manner. This means that any pages may direct the user to select from an index / menu with next / previous request capabilities. A 20,000 pages sequence is broadcasted giving access to specific part of the data base only by authorized users.

The data base is subdivided in many smaller data base defining groups of pages on specific subjects. The sequence of pages broadcasted in a random and asynchronus pattern may be updated any time by the provider of each service. At specific period of the day, particular content are made available based on demand. An important feature is the constant response time that every user gets no matter the number of users accessing the data.

Actually, a keypad is used to control the converter through infra-red communication. This keypad is fully reprogrammable (keys) depending of the mode and service being used and accessed. For instance, as a cable converter different keys do control channel selection, scan of preferred channel, volume control, TV on-off and display of clock and channel number on the screen.

When the user wants to access other services, he asks for the main menu ("?" key) which is displayed in overlay on the TV picture. From that menu the user may select to access to the user's or service's guide, to the videotex data bases, to videogames, to captioning or to software downloading for its home computer or videogames console.

After this selection, the user may select directly one of its preferred service for which he has previously been authorized.

When accessing a PTV program, all validation necessary will take place to verify program tier versus user's tier and decode the program only if a match is found. For program encoding, VIDACOM™ uses a high security of signal processing based on speudo random algorithms that are initialized and controlled by special tagging received as a public key via a different signal from the scrambled video signal and intermixed with other data transmission of VIDACOM™ . The long term security of the unit which is software driven takes care of box thief or pirate boxes that cannot receive the proper signal to decode the scrambled video signal received.

The free format of packet that may be transmitted allow the distribution of videogames softwares and home computers software through a standard interface (RS232C). Presently most of the home computers have been interconnected to the VIDACOM™ system and software can be selectively downloaded to each of them concurrently. Special development are presently on-going for the interfacing of videogames type devices. With this capability, the cable operator can support a broader range of user's terminal defining a broader base for offering software distribution compared to system where only one type of user terminal or software library system is supported.

CONCLUSION

At this point of the field trial, the capability of the VIDACOM™ system to support a diversity of services and contents do permit the conduct of various market research and specific definition of new services adapted to the interests of the users. If these needs change or evoluate with time, it will be possible to modify the mix of these services to respond to specific demand or add new services in the data transmission system.

The user friendly approach supported by an online user's guide for functions or services description creates an environment where the user rapidly "play" with the system. When he requires "help" he only has to use the "?" and instant information is provided.

The capacity of VIDACOM™ to merge video program with information or data contents will shortly offer the capacity of interactive video programs , of video catalog, of video and data related programm and more.

The field trial is conducted over a period that will end at the beginning of 1984 permitting adjustments of software components that will be implemented in the final product which will be offered starting mid 1984. This test bed based on prototypes is available for evaluation or demonstration to other cable operators.

VIDEOTEX ALTERNATIVES IN CABLE

Walter S. Ciciora William L. Thomas

AMERICAN TELEVISION & COMMUNICATIONS CORPORATION
ZENITH RADIO CORPORATION

Introduction

The first videotex alternative determines whether the transmission is broadcast, telephone, or cable. The concentration here is on cable. The reasons for this will be discussed in detail since they are fundamental to understanding cable's substantial advantages over competing media. In cable there are a wide variety of alternatives to consider. Should the videotex service be vertical blanking interval or full field? Will financial support come from advertising or from pay, or both? If a pay structure is chosen will the security be soft, firm or hard? Will the service be tiered and addressable or simply go no-go? Will it be one-way, one-way upgradable, or two-way? Will the display be RF or RGB? Are mosaic graphics adequate, or must geometric graphics be employeed from the very beginning? Plain or fancy?

VBI vs. Full Field

Vertical Blanking Interval (VBI) cable teletext is basically an ancillary service. Like its broadcast cousin, it has limited capability. Unlike the broadcast environment, however, cable has multiple VBI's under the control of the same entity. Thus, tiering can be accomplished by putting information on various subjects on different channels. Cable will not have the multipath problems that broadcast does. The Keyfax service is a right-now example of VBI cable teletext nationally distributed in the Vertical Blanking Interval on Channel 17, WTBS, Atlanta. Keyfax is on exhibit at the convention and equipment is available now on a limited basis. VBI teletext makes the most sense in older cable systems which have 12 to 24 channels and cannot afford a fully dedicated teletext channel. A 12 channel cable system which used its 12 VBI's for separate data services, could offer significantly expanded service without increasing bandwidth. VBI teletext services are available on any systems that carry WTBS, NBC or CBS. Both NBC and CBS are currently broadcasting teletext according to the North American Broadcast Teletext Specification (NABTS). WTBS carries the Keyfax signal which follows the British approach. Unfortunately, two different decoders would be required to receive all three signals. Full field teletext requires the dedication of a complete video channel to the teletext service. In return for this commitment, full field teletext offers tremendous page capacity. Typical systems can carry 500 or more pages per second. This is in contrast to the 4 or 5 pages per second possible in a VBI service. Thus, for a given 10-second maximum wait time, full field teletext has a capacity of 5,000 pages. This contrasts with a 40 or 50 page capacity for a 10-second wait in a VBI system. Two examples of full field teletext systems are at the convention. The Time Videotex Information Service (TVIS), is a full featured, high resolution graphics service with the emphasis on quality contents. Zenith has made available a full field tiered addressable teletext set of equipment with the emphasis on lower cost and more immediate availability. The TVIS system has been created by experts in publishing and information communications. The Zenith system has been created by hardware experts.

Advertise or Pay

Two mechanisms of financial support are proposed. Advertiser support is the more conventional method used in broadcast television. Advertisements are introduced either in a intrusive or non-intrusive manner. The intrusive ads are unavoidable. They appear as messages on a page containing desired information. The non-intrusive ads must be specifically pursued. The advantage of a non-intrusive ad is that it serves a customer with a serious need. The advantage of a intrusive ad is that it attracts attention.

The alternate method of financial support, is a pay service. This is akin to the method of support employed in premium cable services. In order for a pay strategy to be successful, access must be restricted. There are at least three approaches to restricting access. Soft security relies on the scarcity of equipment to restrict access. This technique has been employed by Keyfax. The advantage is simplicity. The disadvantage is that if teletext becomes successful in the broadcast environment, teletext receivers connected to cable will obtain the Keyfax service for free. This will require a change in the Keyfax support mechanism to an advertiser-based approach or a switch out to different hardware. The Zenith system uses a firm security mechanism which introduces a modest amount of scrambling of the data. A commercially purchased broadcast teletext decoder will not be able to decode the Zenith scrambled signal. The ultimate in security and cost is a hard scrambled system based on advanced digital techniques, such as the Digital Encryption Standard, created by the National Bureau of Standards. Soft security has a limited lifetime. One of the principle disadvantages of soft security in a pay system is the fact that stealing the box is very rewarding. It provides free service for the length of time the information provider avoids Chapter 11. Firm security is an economic compromise which restricts access but avoids the cost of true hard security.

Tiered Addressable

The tiered addressable concept is a fundamental lesson learned by the cable industry in recent years. If a service is valuable, it must be controlled by an addressable product; that is, it must be possible to reconfigure the service in the customers home via remote signaling from the cable headend. A valuable service with a large number of options invites the subscriber to change his mind and try different flavors. Eventually, the subscriber tailors the service to his specific needs. In the meanwhile, considerable changes in the service configuration are required. With an addressable product, this represents only a modest operational burden. That burden is justified once the subscriber finds the services that suit his needs. Without addressability, there is a need to visit the subscriber's home each time he wishes to change the configuration of services. This quickly becomes economically untenable. Tiering is the process of dividing the service into segments. Tiering is merely the application of the market segmentation principle. It allows the subscriber to tailor the service to his individual tastes and needs.

The Graphics Choice

The TVIS full field teletext service and the NBC and CBS Vertical Blanking Interval services are based on geometric graphics. High resolution displays provide eye appeal which is felt necessary, particularly in advertiser supported systems. The Keyfax and Zenith systems are mosaic graphics based. Arguments over the relative costs and relative desirability of different graphic systems, have been carried out in the literature and at conferences over the last several years. There is no need to repeat any of that here. The passage of time will determine which approach survives. It is conceivable that the marketplace has room for both.

NTSC vs. RGB Display

Two mechanisms for displaying the teletext information are possible. One mechanism connects the decoder to the antenna terminals of a television set. The other uses a specially modified television set or a video monitor. The latter approach, while more expensive, yields a better display because the red, blue and green guns of the picture tube can be driven directly. The quality of this RGB drive is limited only by the characteristics of the picture tube. Going through the antenna terminals of a television set enforces all of the compromises made in creating the compatible NTSC color television system. The recent availability of video monitors with RGB inputs has been stimulated by the personal computer. The rapid growth of that market and the prolification of RGB monitors, means that better teletext service will be possible on cable with leased equipment. Teletext modules leased by cable companies will likely have both RF and RGB outputs. The subscriber with an RGB monitor will be able to enjoy higher quality displays without the need of buying a new television set which has the teletext decoder built in. The limitations on the antenna terminal connected display are fundamental to the NTSC color television system. Improvements in future color television receivers will not result in significantly better teletext displays, as long as the connection is through the antenna terminals.

One-Way vs. Two-Way

Nearly all cable systems in the United States are one-way. A small fraction of cable systems are capable of being converted to two-way and an even smaller fraction, less than one percent, are operational two-way systems. Fortunately, one-way teletext has a tremendous potential for providing a useful and interesting service. This is particularly true of full field teletext where the numbers of pages are substantial. A bridge between one-way and two-way and a significant enhancement to teletext is telesoftware. With telesoftware computer programs are down loaded into resident personal computers. The subscriber then interacts with the computer program. A one-way system has thus been given interactive capability. Of course, what is still missing is transactional capability; that is, the potential for placing orders and sending information back to the cable headend. Temporarily, much of that need could be served by touch tone telephone key pads. As impulse pay-per-view becomes practial from a technical standpoint, (and an economic standpoint), the same ten-key pad used for impulse pay-per-view can service the need to communicate numerical data to the headend. Thus, a two-way system can be assembled from a fundamentally one-way teletext service and the hardware required for impulse pay-per-view. This will be an evolutionary process where the hardware develops overtime and bridges are built between systems motivated by entirely different needs.

Plain vs. Fancy

The telephone industry has an expression for its basic service - POTS, which stands for Plain Old Telephone Service. We can borrow that term and apply it to teletext. The issue then is Plain Old Teletext vs. Fancy. Very little imagination is required to fancy up the teletext system and obtain truly attractive results. An example of such interesting features is found in the Zenith full field tiered addressable system. Each decoder is capable of responding to a specific page number that all other decoders ignore. This permits the implementation of an electronic mail system. Messages can be sent to an individual decoder carrying subscribers specific information. Examples of information which serve the cable company's needs are billing status reports and messages about new services. In addition to individually addressed pages, group pages are possible. Thus, the cable company can send marketing messages to all subscribers of a given category. Likewise electronic newsletters for specific groups of individuals can be transmitted.

Some Fundamentals

With all the enthusiasm over videotex, it is well to go back to fundamentals from time to time to reestablish a sense of reality. Any videotex service will require (a) an interesting information base, (b) an information provider (c) a manufacturer or origination and transmission equipment, (d) a one-way or two-way transmission medium, (e) a manufacturer of receiving equipment, (f) sales (or leasing) and service organizations for the receiving equipment, (g) willing buyers (or lessors) of the receiving equipment who are also interested in and willing and able to pay for the information, (h) vast pools of capital held by knowledgeable and willing investors who are capable of evaluating the risks and potential rewards of this enterprise, (i) a business plan which convincingly demonstrates that it will work (not just technically), and (j) leadership to make it happen.

While this list seems detailed, it is in actuality cursory. For example, item (e) the receiving equipment manufacturer, is highly dependent on a manufacturer of Integrated Circuits (IC's). These plastic encapsulated, quarter-inch-on-a-side wafers of highly processed silicon make it possible to do the eletronic magic which puts the "video" into "videotex." These IC's contain tens of thousands of transistors each. Depending on which videotex system is under consideration, the number of these IC's can vary from three or four to dozens. Clearly, it takes many person years to design circuits involving tens of thousands of transistors. The usual Alice-In-Wonderland assumption is that it will just happen. This is due to the phenomena of Digital Mania. The mind infected with this malady believes that anything can be done digitally and in three years it will be free. Furthermore, believing will make it so. Digital watches and calculators are the usual "proof" offered for these beliefs.

Entrepreneurial Factors

The entrepreneurial factors, (h), (i), and (j) are the most commonly neglected in any analysis of videotex scenarios. Yet, they influence every step along the way. The most important missing element is the confidence that the end user will perceive a value which is commensurate with his costs. The uncertainty in the estimates of these costs is a serious problem contributing to a lack of confidence. The cost components include receiving equipment price or lease costs, media usage fees, and information prices. The value side of the equation, that is, the benefit or utility offered by videotex is even harder to measure or estimate. The components of utility are the entertainment, the cost savings, and the opportunities created by the information brought via videotex. Until the entrepreneurs are confident that this cost:perceived value equation is balanced, they will not proceed. They won't create the scenarios and exercise the leadership which will tap the pools of capital so necessary to provide the required investments. Certainly, the high cost of money (interest rates) adds to the risk.

Broadcast Teletext

World-wide, the most successful videotex service at the present time is broadcast teletext. Specifically, the mullard chip set is employed in about two million teletext receivers. One could naturally assume that this means that broadcast teletext will be most likely to lead the videotex race in U.S.A. There are several major differences between the U.S. and the European experience which may invalidate this assumption.

Firstly, the signal environment in the U.S. is much less hospitable than in Europe. Rather than two or three programs with a thousand repeaters, there are a thousand stations with almost no repeaters. This translates into a situation in the U.S. where nearly everyone receives several low quality signals and maybe one or possibly two quality signals. This is instead of the European situation where almost everyone is in a quality signal environment. The signal quality impairments include low signal levels, co-channel and strong adjacent channel interference, multipath (or ghosting) distortion and a wide range of transmitter and broadcast antenna quality and condition. Receiving antenna problems still further complicate the issue. Since much of the U.S. programming takes place on VHF, antennas must be much larger for the same amount of directivity. Conversely, the same number of "pounds of iron" will yield a less directive antenna with VHF when compared to UHF reception. This lack of directivity is most harmful in high multipath situations, such as large cities. The average quality of antenna installation is lower in the U.S. This is due to the relatively low cost of television receivers. An installed quality UHF/VHF antenna and downlead could easily exceed half the cost of the color receiver. In Europe, where receivers have been relatively more expensive the cost of a quality UHF antenna installation is a modest percentage of the receiver price and a prudent investment at that.

The most difficult signal parameter impairment to deal with is multipath or ghosting. Weak signals are relatively easily handled by the digital nature of teletext. The second most serious threat is impulse noise. U.S. standards for motor brush noise and ignition noise are much less stringent than in Europe. And motors and gas engines are in countless electric home and garden appliances. Anyone with a teenage daughter who has a hair dryer can well appreciate this.

Experience has shown that even the inherently more rugged defined format teletext system used in most European teletext receivers experiences difficulty in the broadcast environment of the U.S. This situation would be even more difficult using the variable format schemes also proposed in the U.S. Proposals have been made for error detection methods to patch over these deficiencies. However, these proposals require the addition of more overhead data bits which further reduce the information carrying capacity of an already limited system.

The visibility of retrace lines on color TV receiver models in current production, limit the number of Vertical Blanking Interval (VBI) lines available in the broadcast teletext service to a precious few. The consequence of this is a no-win choice between limited information presented with modest waiting times and adequate amounts of information with mind numbing delays. High resolution graphics techniques such as Picture Descriptor Instructions (PDI's) aggravate the situation by increasing the transmission time per page while increasing the vulnerability to error. This was well demonstrated in the Washington D.C. trials over station WETA. Error protection adds cost and transmission delay. It further presents an unhappy choice: a) wait until all data has been correctly received before creating a picture, or b) paint the picture in steps with interspersed delays until it is complete. The waits in a noisy or distorted signal environment can be severe. A note here about "microprocessor-based" systems is in order. Since microprocessors have limited speed, the data must be sent in bursts so they can be digested before display. Since PDI's must be sequentially painted on the screen (i.e., loaded into the bit plane memory) a missed segment causes a delay for a full transmission cycle until the missed segment can be correctly executed. The alternative is complete buffering of the data.

The above discussion implies that the broadcast teletext service in the U.S. must be inherently limited -- much more limited if extensive high resolution graphics are employed. The cost situation further unbalances the "cost:perceived value equation". Even if the teletext decoder were free, the added cost of a quality antenna installation itself may exceed the perceived value of such a limited service. And, of course, the teletext decoder is not free. Depending on the system chosen, the decoder can be very expensive indeed.

If this wasn't enough, the standards issue is yet one more problem. The usual U.S. standards setting mechanism has failed. Customarily, the Electronic Industries Association (EIA) proposes a standard to the Federal Communications Commission (FCC) which studies, modifies and approves it as the law of the land. This failure is probably because the standard questions involved are too complex for committee decision. In fact, most of the controversy in th EIA Teletext Committee has been over issues of marketplace desire. What are the relative tradeoffs between graphics resolution, cost and waiting time? It may be wiser in issues as complex as this to let the marketplace choose between several choices than to pick between just two choices: a) the committee's guess, and b) rejection of the whole idea. In either case, it will be a marketplace decision. In the first case the market has multiple choices, in the latter, just two: "yes" or "no".

Telephone Interactive Videotex

The principal inhibiting factor with telephone-based, two-way interactive videotex is that the medium over which the message itself travels has a usage cost associated with it. To use the telephone terminology, the Public Switched Network (PSN) is rapidly going to Universal Measured Service (UMS). There is good reason to fear that the usage cost will absorb most of the available disposable consumer income. This will leave little if anything for the receiving equipment lease fee, the information purchase, and the share of the originating equipment. Information providers believe they're going to get the usual cable TV revenue split, the cost of telephone interactive videotex will be prohibitive. Another difficulty is in the nature of the PSN itself. The architecture of the PSN is statistically designed based on certain assumptions as to number of calls and length of calls, i.e., hold times. The hold time statistics are likely to be significantly upset by interactive videotex. The success of interactive telephone videotex may be self-limiting by the problems it can cause on the PSN. Longer times until dial tone, more frequent busy signals, and less availability of the phone for its conventional use are just some of the ramifications.

Another serious concern with two-way videotex is that the cost of computer facilities on a per user basis may be a substantial percentage of the total cost. In sharp contrast to broadcast teletext where origination hardware cost is the same for one user as millions, subscriber growth for telephone interactive videotex necessitates origination computer growth.

The two principal advantages of two-way interactive telephone-based videotex as compared to broadcast teletext are: a) access to a much larger data base, and b) transactional services, such as shopping, banking, and electronic mail. As will be discussed below, a much more cost effective means of transporting larger volumes of information is one-way, full field cable television. The second advantage listed above brings serious concerns about security, privacy, and the interface to other computers.

One Way Cable Teletext

Probably the most promising videotex technology in the U.S.A. today is one-way cable TV teletext. The reasons are:

a) no multipath or ghost problems,

b) significantly better overall signal quality,

c) spectrum availability for full-field use,

d) the ability to limit access and thus charge for the service,

e) the ability to segment the market through tiered addressable services,

f) one-way electronic mail with firm security thru addressability,

g) a preselected market of video-oriented potential customers,

h) a market already accustomed to receiving equipment leasing,

i) the relative unimportance of standards,

j) the future upgradeability to two-way interactive services,

k) the present ability to do a hybrid two-way thru telephone "ten-key" requests.

More than half of television households are passed by Cable TV in the U.S.A. More than half of these subscribe. Thus, about 30% or 28 million subscribers now have cable. And the growth rate is aggressive.

The new modern cable systems provide excellent signal quality on from thirty-five to sixty channels. Currently, 440 MHz dual cable systems are being installed in major markets providing a total of 120 television channels. Both signal quality and spectrum availability disappear as issues in these cases. Thus, not only are the 120 VBI's at the cable operator's disposal, but he can partition them according to his needs. In the broadcast arena this is not possible because of the difficulty of orchestrating the level of co-operation between the various owners of the VBI's in a given market and the anti-trust legal questions.

The most exciting cable opportunity is a full field, tiered addressable service. Rather than just four to eight lines in the VBI, over 500 are available. This yields a page rate of over 500 per second. This can be combined with cable's addressing techniques so that each box can be controlled from the cable headend. Furthermore, the service can be partitioned into separate services each of which can have individual subscriptions. Thus, the subscriber can choose between various teletext magazines covering general news, sports, financial, entertainment, etc. He can select and pay for only the services he desires. The addressable nature of the product allows control of reception from the headend. Thus, even if the subscriber frequently changes his mind, his receiving equipment can be reconfigured to match his changing tastes.

The cable subscriber is already accustomed to monthly bills for service and equipment leasing. The teletext service is thus incremental. It does not require the subscriber to adopt a new way of thinking about the service.

An interesting by-product of addressability is being able to send individual pages to each subscriber. This is possible even though the cable system is not a switched network. Electronic mail distribution is thus possible in even a one-way system. The first application is subscriber notification of billing and account status. This can be extended to include "telegram" like service where the messages are phoned into the cable company and then sent to the individual teletext receivers.

Since each cable system is a universe unto itself, the need for national standards is obviated. The digital nature of videotex facilitates translation of information between various protocols.

The one-way cable system can begin to have some two-way capability through the use of the touch tone telephone keypad and appropriate computer interfacing at the cable headend. Thus, an even larger data base can be available with two kinds of pages: a) those that normally reside on the teletext repeating cycle, and b) those that get requested individually. A statistical tabulation can be used to decide when to convert type "b" pages to type "a" pages and vice versa.

Two-Way Interactive Videotex and Cable

In addition to cable's advantages listed above, cable has the promise of two-way. This promise is realized in less than 1% of U.S. cable systems at present. Significant technical, operational, and economic difficulties remain. However, true two-way is a promise broadcast can't even contemplate.

Cable's two-way is not a switched system as is the telephone network. However, electronic message switching schemes accomplish the same result at much less hardware cost at the expense of bandwidth. But bandwidth is cable's principle available resource. Because of the bandwidth, usage sensitive pricing will not be necessary for the foreseeable future.

The telephone disadvantages with regard to origination computers apply to cable as well with one important difference. Since cable videotex will have an integral one-way teletext service, the quantity of two-way pages can be significantly less. These would be limited to only the less popular pages. The tens of thousands of more popular pages would be delivered via one-way.

It is important to keep a realistic view of cable two-way. It is not a present reality. It now exists only as either a very limited non-videotex-compatible service or as a field trial.

Conclusion

The creator of a videotex system for cable has many alternatives to choose from. This makes the task interesting. Several examples of cable videotex systems exist now and the cable community should study the differences. Cable videotex is imminent and the time to learn about the choices is now.

The good news this paper tries to convey to its audience is that videotex is most naturally a cable service. Cable has a number of significant advantages over rival media such as broadcast and telephone.

ISBN 0-940272-01-6; 0-940272-08-3; 0-940272-10-5; 0-940272-11-3; 0-940272-12-1; 0-940272-14-8; 0-940272-15-6; 0-940272-16-4; 0-940272-18-0; 0-940272-19-9; 0-940272-20-2; 0-940272-21-0; 0-940272-22-9; 0-940272-23-7; 0-940272-24-5; 0-940272-25-3; 0-940272-26-1; 0-940272-27-X; 0-940272-28-8; 0-940272-29-6; 0-940272-32-6; 0-940272-33-4; 0-940272-34-2; 0-940272-35-0; 0-940272-36-9; 0-940272-37-7; 0-940272-38-5; 0-940272-39-3; 0-940272-40-7; 0-940272-41-5; 0-940272-42-3; 0-940272-43-1; 0-940272-44-X; 0-940272-45-8; 0-940272-46-6; 0-940272-47-4; 0-940272-48-2; 0-940272-49-0; 0-940272-50-4; 0-940272-51-2; 0-940272-52-0; 0-940272-53-9; 0-940272-54-7